# Protecting Critical Ecosystems: Current EPA Regional Activities and Future Agency Opportunities

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# Appendices

The following three appendices contain additional resources relevant regional critical ecosystem assessments.  Appendix A is an inventory of additional projects and other information that is organized by project/resource.  These project, research, and tool descriptions can be used to identify data, analytical techniques, and tools that can be used to enhance future assessments of critical ecosystems by improving data, techniques, and closing gaps.  Appendix B includes websites, citations, and data lists that are organized by the SAB Framework Essential Ecological Attributes to serve as sources of information for conducting analyses relevant to identifying critical ecosystems for each category of analysis.  Appendix C is a condensed version of thesis project conducted by Ginevra Lewis, part of the University of Florida research team.  Her research reviews methods for assessing wetlands for suitability/significance for mitigation and develops indices for prioritizing wetlands based on landscape, habitat, and other characteristics.  Many of these indices could be relevant to critical ecosystem identification in other regions.

# Appendix A: Inventory of Additional Current Projects, Research, Data, and Analytical Tools Relevant to Regional Assessments of Critical Ecosystems

## 1) Additional U.S. EPA Projects and Tools

### a. Regional Vulnerability Assessment Program (ReVA)

Smith, E.R., R. V. O'Neill, J.D. Wickham, K.B. Jones, L. Jackson, J.V. Kilaru, and R. Reuter. 2000. *The U.S. EPA's Regional Vulnerability Assessment Program: A Research Strategy for 2001 - 2006*. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC. 52 pp.

U.S. Environmental Protection Agency. 2003. *Regional Vulnerability Assessment Program*. [Online] Retrieved May 4, 2004 at http://www.epa.gov/reva/.

The Regional Vulnerability Assessment (ReVA) Program is a program of the U.S. EPA Office of Research and Development (ORD) that is developing approaches to regional ecological assessment. The program is focusing on the collection, management, and analysis of data sources to evaluate environmental conditions and stressors in order to target risk management activities. An objective of the program is to provide spatially explicit information, at the regional scale, on the extent and distribution of both stressors and sensitive ecological resources. The Mid-Atlantic region is the current focus of the program, as part of the Mid-Atlantic Integrated Assessment (MAIA), which is a federal, state and local partnership led by U.S. EPA, Region 3. Other regions will be targeted in the future. Research will concentrate on exposure to stressors and effects that stressors have on ecological processes at the regional scale. The following stressors will be targets of research: 1) land-use change and population growth, 2) resource extraction (including over-fishing of both fin and shellfish, timber harvest, and mining), 3) pollution (including urban non-point source pollution, agricultural runoff, atmospheric deposition), 4) non-indigenous species, and 5) cumulative impacts of climate change, non-indigenous species, increased development and air pollution. The extent and distribution of the following resource categories and their vulnerability to stressors will be examined: 1) forests (productivity, health, sustainability of native species), 2) streams (designated use, water quality, sustainability of native species), 3) Groundwater, 4) Wetlands, 5) Human health, 6) economics, 7) estuaries, 8) agriculture. The first step of the program will be to develop spatial data sets for the Mid-Atlantic assessment area. The data will include infrastructure (e.g., roads), stressors (e.g., atmospheric deposition and chemical inputs), landscape characterization data, sensitive resources (e.g., wetlands), and ecological endpoints (e.g., avian biodiversity). The data will be retained at the finest resolution available to ensure that assessments may be reported at a variety of spatial scales including regional, watershed, and local scales. The use of existing available data will be emphasized and obtained from the following regional databases: Mid-Atlantic Landscape Atlas, ReVA Stressor Atlas, and the Index of Watershed Indicators (IWI) (http://www.epa.gov/iwi/). Indicator research will be conducted to fill critical gaps in

data.  The next step of the program will include the development of additional coverages derived from the primary spatial data.

**b.  WebRIT WATERS**

Rineer, J., A.M. Miller, T. Dewald, and M. Plastino. Date unknown. *Georeferencing to the NHD: Moving from ArcView to ArcIMS*.  [Online] Retrieved May 4, 2004 at http://gis.esri.com/library/userconf/proc02/pap0467/p0467.htm.

U.S. Environmental Protection Agency.  2003.  *WebRIT WATERS*.  [Online] Retrieved May 4, 2004 at http://www.epa.gov/webrit/.

WebRIT WATERS (Web-based Reach Indexing Tool for the Watershed Assessment, Tracking, and Environmental Results) is a geospatial tool with internet map-based capabilities for data entry, validation, updating National Hydrography Dataset (NHD) reach addresses, working with latitudes and longitudes and other spatial information.  It is available to U.S. EPA partners such as States, Tribes, local municipalities, and regulated entities and allows partners to submit, verify, and update locational data.  WebRIT WATERS is a web-based tool designed to incorporate many of the features of its forerunner, the National Hydrography Dataset Reach Indexing Tool (NHD-RIT).  NHD-RIT was developed as a standalone ArcView system, and WebRIT WATERS will contain many of the same ArcView based features.  The tool can support a large number of users from different EPA programs and provide for the collection of multiple types of data, including linear data, point data, and polygonal data.  WebRIT WATERS will also act as a centralized database for data collection from multiple users. The interface is also designed to be simple to use.

**c.  Analytical Tools Interface for Landscape Assessments (ATtILA)**

Harrison, J., D. Ebert, T. Wade, and D. Yankee.  2000.  *Using ATtILA (Analytical Tools Interface for Landscape Assessments) to estimate landscape indicators and target restoration needs*.  Office of Research and Development, U.S. Environmental Protection Agency, 10 pp.  [Online] Retrieved May 18, 2004 at http://www.nwqmc.org/2000proceeding/papers/pap_harrison.pdf.

U.S. Environmental Protection Agency.  2001.  *ATtILA: Analytical Tools Interface for Landscape Assessments*.  [Online] Retrieved May 18, 2004 at http://www.epa.gov/nerlesd1/land-sci/tools.htm.

The U.S. EPA Office of Research and Development has developed an ArcView extension, the Analytical Tools Interface for Landscape Assessments (ATtILA) that facilitates the generation of landscape metrics including landscape characteristics, riparian characteristics, human stressors, and physical characteristics.  Landscape characteristic metrics use land use/land cover data such as MRLC (Multi-Resolution Landscape Characterization **NLCD**), SAA (Southern Appalachian Assessment), and other data such as aerial photography derived data.   Any available analysis boundaries

may be used including watersheds, hydrologic units, ecological regions, counties and others.  Landscape characteristic metrics include total area and percentage of the following: crop land, pasture, all agricultural uses, barren, forest, urban, user defined class, wetland, all natural land use, all human land use, agricultural crop land on steep slopes, agricultural pasture on steep slopes, and user defined class on steep slopes. Riparian characteristic metrics use land cover data and line coverages of streams. Metrics include percentage of stream length adjacent to the following: crop land, pasture, all agricultural use, barren, forest, urban, user defined class, wetland, all natural land use, and all human land use.  Human stressor metrics use land use/land cover data, census population data, and road and stream line coverages.  Metrics include the following: phosphorus loading, nitrogen loading, population density, change in total population, impervious cover based on land use, road density by road class, total road length by class, number of road/stream crossings by road class, percentage of impervious cover based on road density, and length of roads in close proximity (user defined distance) to streams by class.  Physical characteristics metrics use rainfall estimates for precipitation factors, digital elevation models (DEMs), and stream line coverages.  Metrics include the following: precipitation range; elevation range; elevation of point locations; slope range; stream density; total stream length; and minimum, maximum, average, and standard deviation of precipitation, elevation, and slope.  Three types of output display are available: ranking by individual metric value, weighted index of two or more metrics, and a bar chart of selected areas and metrics.  ArcView version 3.1 (or a later version) and Spatial Analyst version 1.1 extension are required to run ATtILA.  A version of the extension that is compatible with ArcGIS is expected to be available by September, 2004. For further information about ATtILA, contact:

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**d.  Community Based Ecological Protection (CBEP)**

U. S. Environmental Protection Agency. 2000. *Environmental Planning For Communities: A Guide To The Environmental Visioning Process Utilizing A Geographic Information System (GIS)*. Office of Research and Development. Cincinnati, OH. EPA/625/R-98/003. [Online] Retrieved 12/09/2003 at http://www.epa.gov/ORD/WebPubs/gis/.

Summary:
        For many of its ecosystem protection programs the US EPA has shifted to a Community Based Ecological Protection (CBEP) approach, which allows input from

local stakeholders on community-wide environmental issues. This methodology uses environmental visioning whereby alternative, future scenarios of landscape evolution are creating using GIS-based methods for modeling and assessing what-if situations. This guide provides methods for using GIS in the context of environmental visioning. A brief history of GIS is provided, along with software and hardware requirements, and data sources required to construct a GIS database for a particular modeling and visioning application. The CBEP is a comprehensive ecosystem management and planning approach promoted by EPA, to assess and manage the quality of air, water, land and living resources in an area in a "holistic context." This approach has been developed and employed to better reflect the unique needs and requirements of regional and local conditions and to stimulate and promote a more effective partnership with local communities, and is designed to maximize the use of scarce resources, encourage local support, consider the economic well being of communities, and allow EPA to work in partnership with residents to solve environmental problems. CBEP partnerships may include representatives from all levels of government, public interest groups, industry, academia, private landowners, concerned citizens and others."

Spatial Extent: Methods are independent of a specific spatial extent; three case studies are given inclusive of the following: West Muddy Creek, Benton County, Oregon (http://ise.uoregon.edu/Muddy/Muddy_abstract.html); Monroe County, Pennsylvania (http://www.gsd.harvard.edu/depts/larchdep/research/monroe); and Camp Pendleton, California (http:// www.gsd.harvard.edu/brc/brc.html).

Analysis Categories:
From case studies:
West Muddy Creek, Benton County, Oregon: SAB categories include Biotic Condition (subcategory Species and Populations), and Chemical and Physical Characteristics (subcategory Nutrient Concentrations). Stressors addressed include nutrient enrichment and land use change.

Monroe County, Pennsylvania: SAB categories include Landscape Condition and Biotic Condition (subcategories Ecosystems and Communities and Species and Populations).

Camp Pendleton, California: SAB categories include Landscape Condition and Biotic Condition (subcategories Ecosystems and Communities and Species and Populations). Stressors addressed include alteration of natural process regimes and land use change.

GIS tools:
A GIS based biodiversity model was created for West Muddy Creek, Benton County, Oregon project.
Tools used for Monroe County, Pennsylvania study included interpreted satellite images, infrastructure plans, field notes, GIS maps of the current ecosystem condition, and maps of alternative land development practices
The tools used in the Camp Pendleton study included GIS aided analytical models for simulation of the processes involving hydrology, soils, fire, visual preference, and biodiversity.

### e. An Ecological Assessment of the United States Mid-Atlantic Region: A Landscape Atlas

U. S. Environmental Protection Agency. 1997. *An Ecological Assessment Of The United States Mid-Atlantic Region: A Landscape Atlas*. Office of Research and Development. Washington, DC. EPA/600/R-97/130. [Online] Retrieved 12/16/2003 at http://www.epa.gov/emap/html/pubs/docs/groupdocs/landecol/atlas/atlas.html.

Summary:
       This atlas was created to assess the environmental condition of Region3 using a watershed approach of landscape indicators of watershed condition. This approach draws from landscape ecology whereby the condition of the environment and human activities are evaluated together. These indicators, appropriate for regional extent analyses, are derived from geospatial data consisting of satellite imagery and GIS data of the region. Based on watershed indicators alone, relative to all other watersheds in the mid-Atlantic region, the watersheds in southeastern Pennsylvania and the northern end of the Chesapeake Bay have consistently lower values for all of the landscape indicators. Conversely, there are a few watersheds in southwestern and north-central portions of the region that have consistently higher scores across all the indicators. Using nine of the 32 watershed indicators to avoid cross correlation, statistical cluster analysis was performed to group watershed into categories of environmental quality. In general the results indicate watersheds with high human populations and low habitat indicators are in less desirable environmental condition, while watershed with high environmental condition have low human populations and high habitat indicators.

Indicators:
Population Density and Change; Human Use Index (urban or agriculture); Roads; Air Pollution; Landscape Units (forest, agriculture, and developed land); Water and Riparian Indicators; Forest and Agricultural Land Cover; and Roads Along Streams; Watershed Indicators; Impoundments; Agriculture on Steep Slopes; Nitrogen and Phosphorus Export to Streams; Soil Loss; Forest Land Cover (Fragmentation; and Interior Forest and Edge Habitat); Largest Forest Patch/ Forest Land Cover; Landscape Change (1975–1990), Vegetation Change Among and Within Watersheds (1975–1990), and Vegetation Loss on Steep Slopes (1975–1990) using Normalized Difference Vegetation Index (NDVI).

Spatial Extent:
Region 3 (Pennsylvania, Virginia, West Virginia, Maryland, Washington DC, and Delaware)

Analysis Categories:
SAB categories: Landscape Conditions and Chemical and Physical Characteristics
Stressors (alteration of natural process regimes and land use change)

GIS tools:
Spatial overlays using raster data (Map Algebra), and spatial filtering.

USGS - HUC 8 digit codes 1:250, 000

DLG streams and roads, 1:100,000

USGS 30m DEM

Multi-Resolution Land Characteristics Consortium (MRLC) – land cover/land use Landsat Thematic Mapper satellite data 30m aggregated to 90m.

U.S. Census Bureau – population on county extent (scale unknown)

U.S. Department of Agriculture (USDA) – soils (scale unknown)

Indicators:

*Population Density and Change*: United States Census Bureau population statistics from 1970 and 1990, and US Geological Survey, 1:100,000–scale Digital Line Graphs —— Transportation; value range: 0< pop/km2<400+, -0<%change<180+

*Human Use Index* (urban or agriculture)- MAIA Landcover derived from Landsat TM satellite imagery with 30m cell resolution: value range low to high; 0<%<100

*Road density*: U.S. Geological Survey, 1:100,000–scale Digital Line Graphs - Transportation: ranking: road length per watershed area; value range:0< km/km2<10+

*Air Pollution*; based on regional scale models developed by J. Lynch, Penn State University, and A. LeFohn, Asle and Associates: nitrate (value range 0< kg/Ha*100<2200+) and sulfate (value range 0< kg/Ha*100<4000+) deposition; ozone index: (value range 0< W126 Index<75+)

*Landscape Units* (forest, agriculture, and developed land): USGS NLCD: categorical ranking based on pure and mixture of landscape units

*Forest and Agricultural Land Cover*: USGS NLCD; value range 0<percentage forest/agriculture along total length of streams in a watershed <100

*Roads Along Streams*: U.S. Geological Survey, 1:100,000–scale Digital Line Graphs - Transportation: value ranges 0<%Stream length within forest landcover/total stream length within watershed<100; 0<percentage of stream length within 30 miles of road<20+

*Impoundments*; USGS Dam locations: value range 0<dams/1000km of stream<100+

*Agriculture on Steep Slopes*: USGS NLCD and DEM: value range 0<percent of agriculture and crop land on slopes greater than 3%<30+

*Nitrogen and Phosphorus Export to Streams*: value ranges N 100<kg/Ha/yr<1000+; P 15< kg/Ha/yr<150+

*Soil Loss* based on the Universal Soil Loss Equation (National Resource Conservation Service STATSGO soil data, USGS DEM, USDA Agricultural Handbook 537): value range 10<percent soil eroded from agricultural land cover<100

*Forest Land Cover* (Fragmentation; and Interior Forest and Edge Habitat): value ranges 10<percent forest cover within watershed<100; 10<percent forest fragmentation within watershed<100; 10<percent forest edge habitat within watershed at 7, 65 and 600 Ha windows<100; 10<percent interior forest habitat within watershed at 7, 65 and 600 Ha windows<100;

*Largest Forest Patch/ Forest Land Cover*: value range 0<proportion of watershed in anthropogenic land cover<1

Landscape Analysis using Normalized Difference Vegetation Index (NDVI).

*Landscape Change* (1975–1990): value range 1<%<30.5

*Vegetation Change Among and Within Watersheds* (1975–1990): value ranges 1.2<%<26.1; 2.2<%<45.9
*Vegetation Loss on Steep Slopes* (1975–1990): value range 0<%<16

### f. Guidelines for Ecological Risk Assessment

U. S. Environmental Protection Agency. 1998. *Risk Assessment Forum. Guidelines for ecological risk assessment*. EPA/630/R-95/002F. [Online] Retrieved 12/16/2003 at http://www.epa.gov/ncea/ecorsk.htm.

Summary:

These guidelines will improve the quality of ecological risk assessments implemented by the EPA while improving the consistency at which they are executed among the EPA's program offices and regions. These guidelines draw upon the 1992 report *Framework for Ecological Risk Assessment* while maintaining a broad scope applicable to regional studies. The assessment is conducted using problem formulation, analysis, and risk characterization. Problem formulation, the foundation of the assessment, consists of development of an analysis plan encompassing establishment of assessment endpoints, choice of conceptual model and goal evaluation. Exposure to stressors and relationships between stressor levels and ecological effects are investigated during the analysis component, consisting of the interaction between the characterizations of exposure and ecological effects. Lastly, risk characterization involves risk estimation and description, and reporting results and implications in a report whereby evidence of and confidence in risk assessments are provided. Afterwards, ecological mitigation and monitoring plans may be established along with observations of potential ecological recovery.

An example application of this method focuses on the ecological risk assessment of low water elevations for three distinct habitats in Lake Verret Basin, Louisiana. Artificial levee construction is cited as the primary stressor and "assessment endpoints included forest community structure and habitat value to wildlife species and the species composition of the wildlife community." This stressor was evaluated in conjunction with sediment deposition at the mouth of the river using a model FORFLO to simulate extent and frequency of flooding. Additionally, alterations to plant communities over time were assessed with the model, which indicated that the flooding caused vegetation changes.

Spatial Extent:
Regional extent (generally applicable);

Analysis Categories:
SAB categories: Landscape Condition, Biotic Condition (subcategory Ecosystems and Communities), Hydrology and Geomorphology

GIS tools:
From example: The FORFLO model to assess plant community responses to extent and frequency of flooding due to levee construction, which caused subsidence and decreased stream gradient.
GIS data layers of habitat types under investigation: wet bottomland hardwoods, dry bottomland hardwoods, and cypress-tupelo swamp.

### g. Watershed Information Management System (WIMS)

U. S. Environmental Protection Agency. 1997. *Designing an Information Management System for Watersheds.* Office of Water (4503F) Washington, DC 20460. EPA841-R-97-005. [Online] Retrieved 12/16/2003 at http://www.epa.gov/owow/watershed/wacademy/its05/.

Summary:
    This report provides a detailed overview for the design, implementation, and management of geographic information system for watershed and hydrologic analyses through a seven-step process for a watershed information management system (WIMS). In general, this process can be subdivided into seven major components including establishment of an information management design and implementation team, conducting a survey watershed planning partners, identification and prioritization of data needs, integration of existing databases and development of new databases, evaluation of hardware and software configurations, evaluation of organizational, staffing, and support issues, and development of short- and long-range implementation plans. This report provides good information about responsibilities of each member of a watershed management staff. Most recommendations about the planning, organization and implementation of a WIMS seem practical. Current industry standard GIS packages like ArcGIS 8.3 are commonplace in many regulatory agencies. However, appropriate numbers of staffing familiar with GIS processes and software may be lacking in some offices. The recommended hardware capabilities and cost are outdated as the technological capabilities of computers are ever changing and improving continuously.

Spatial Extent:
None specified.

SAB Reporting Categories:
None specified.

GIS Tools:
A general description is provided about GIS concepts, software and hardware configurations.

### h. Source Water Assessment Using Geographic Information Systems

Bice, L.A., R.D. Van Remortel, N.J. Mata, and R.H. Ahmed. 2000. *Source Water Assessment Using Geographic Information Systems*. National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. [Online] Retrieved 12/09/2003 at http://www.epa.gov/ORD/NRMRL/wswrd/gis.htm.

Summary:

      With regard to the Safe Drinking Water Act of 1996, the Source Water Assessment Program (SWAP) is employed to reduce the risk of contamination due to the degradation of source waters by chemical, biological, physical and radiologic degradation. Goals of the EPA's SWAP include the following: delineate protection areas for drinking water intakes, identify and inventory significant contaminants in the protection areas, and determine the susceptibility of the public water supply (PWS) systems to the contaminants in the protection areas. This report acts as a guide for states, municipalities, and public water utilities for assessing source waters using geographic information system (GIS) technology. Appendices include descriptions of three case studies demonstrating the use of selected GIS-based software and hydrologic models to conduct hypothetical source water evaluations. The fundamentals of GIS are provided with an emphasis on data types, accuracy and creation; analysis techniques; and available software as well as hardware requirements, which flexible in description to change with technology. Reference to data types, analyses, software and hardware needs are provided for remote sensing based SWAP analyses. The process of source water assessment involves design and construction of the GIS database (study area delineation and characterization and map projection, coordinate system and datum, data needs and inventory, and GIS infrastructure), and data analysis (risk assessment of contamination source, and proximity analysis and protection area delineation). An overview of software support tools is provided including appropriate applications, constraints and advantages, results and products, source and cost, and operational requirements of commonly used hydrologic modeling software and packages, and hydrologic analysis tools.

Spatial Extent:
Watershed scale source water assessments at the eight-digit hydrologic cataloging unit code.

Categories of Analysis:
This report addresses the following SAB categories: Chemical and Physical Characteristics of Water (all sub categories), Hydrology and Geomorphology (Sediment and Material Transport).

GIS Data and Tools:
Better Assessment Science Integrating Pointy and Nonpoint Sources (BASINS)
BASINS Stream Water Quality Model - QUAL2E
BASINS Stream Water Quality Model - TOXIROUTE Model
BASINS Nonpoint Source Model (NPSM)

Riverine Emergency Management Model (REMM) Model
Watershed Modeling System (WMS) Software
Underground Storage Tank (UST)-Access Software
Spatially Referenced Regressions on Watersheds (SPARROW) Model
ArcView Spatial Analyst Hydrology Extension Software
MassGIS Watershed Tools for ArcView Spatial Analyst

**i.  Index of Watershed Indicators**

U.S. Environmental Protection Agency. 2002. *Index of Watershed Indicators: An Overview.* Office of Wetlands, Oceans, and Watersheds. [Online] Retrieved 12/16/2003 at http://www.epa.gov/wateratlas/geo/maplist.html and retrieved 12/15/2003 at http://www.epa.gov/iwi/.

Summary:
      The EPA objectives of this project include the development of a more descriptive method for characterizing the vulnerability and conditions of watersheds at the national level, to make available to better inform the public about the condition and vulnerability of their water resources, and to establish a baseline of watershed condition and vulnerability against which to compare future impacts and measure goal of progress towards preservation and protection of aquatic resources. A suite of indicators are developed to assess watersheds, a hydrologic landscape unit partitioning naturally by topography and a drainage outlet, which include eight to assess watershed condition as a function of water quality, contaminated sediments, and wetland loss; and seven to assess vulnerability indicated by pollutant loads, urban and agricultural runoff, population change, estuarine and species susceptibility, and hydrologic modification. Each of these fifteen indicators can be represented as GIS data layers in a spatial overlay analysis. Detailed analysis flowcharts are provided showing the exact method of determining each indicator from the respective data layer.

Spatial Extent: 8 digit HUC watersheds at the national extent.

Categories of Analysis:
SAB categories: Chemical and Physical Characteristics, Hydrology and Geomorphology, Biotic Condition (subcategory Species and Populations), and Ecological Processes (subcategory Nitrogen and Phosphorus Cycling).
Stressors addressed include physical change.

GIS tools:
GIS spatial overlay
Generated datasets:

Percent of Assessed Rivers, Lakes, and Estuaries Meeting All Designated Uses (1994, 1996, & 1998) - Latest State Information Reported
   *Data Source:* National Water Quality Inventory: 1996 Report to Congress U.S. Environmental Protection Agency, Office of Water. Washington, D.C. April 1998. EPA EPA841-R-97-008.

National Water Quality Inventory: 1994 Report to Congress U.S. Environmental Protection Agency, Office of Water. Washington, D.C. December 1995. EPA EPA841-R-95-005.

National Assessment Database U.S. Environmental Protection Agency, Office of Water, 1996

National Assessment Database U.S. Environmental Protection Agency, Office of Water, 1994

Waterbody System Data Individual State 305(b) Coordinators, 1996

Waterbody System Data Individual State 305(b) Coordinators, 1994

Fish and Wildlife Consumption Advisories (1998) (new data and maps)

*Data Source:* U.S. EPA Office of Science and Technology

Indicators of Source Water Condition for Drinking Water Systems (1990 - 1999, new data and maps)

*Data Source:* U.S. Environmental Protection Agency

Contaminated Sediments (1980 - 1993)

*Data Source:* U.S. EPA Office of Science and Technology, Standards and Applied Science Division

Ambient Water Quality Data - Four Toxic Pollutants (1990-1998) and Ambient Water Quality Data - Four Conventional Pollutants (1990-1998)

*Data Source:* STOrage and RETrieval System (STORET), 1990-1998 U.S. Environmental Protection Agency, Office of Water.

Wetland Loss Index (1780s - 1990s)

*Data Source:* Natural Resources Inventory (NRI), 1982 and 1992.

Dahl, T.E. 1990. Wetland Losses in the United States, 1780s to 1980s. U.S.D.I. Fish and Wildlife Service, Washington, D.C., 21p.


Aquatic / Wetland Species at Risk (1996)

*Data Source:* State Natural Heritage Data Centers and The Nature Conservancy

Toxic Loads Over Permitted Limits (1999; new data and maps)

*Data Source:* Permit Compliance System (PCS), U.S. EPA From the 1999 self-monitoring measurement data reported on the NPDES DMR form

Conventional Loads Over Permitted Limits (1999; new data and maps)

*Data Source:* Permit Compliance System, U.S. Environmental Protection Agency, from the 1999 self-monitoring measurement data reported by NPDES Discharge Monitoring Report (DMR) form.

Urban Runoff Potential (1990)

*Data Source:* U.S. Environmental Protection Agency, Office of Water

Index of Agricultural Runoff Potential (1990 - 1995)

*Data Source:* U.S. Department of Agriculture, NRCS

Population Change (1980 - 1990)

*Data Source:* U.S. Census Bureau

Hydrologic Modification Caused by Dams (1995 - 1996)

*Data Source:* U.S. Army Corps of Engineers

Estuarine Pollution Susceptibility Index (1989 - 1991)

*Data Source:* Coastal Assessment Framework. Digital boundary files. National Oceanic and Atmospheric Administration (NOAA), 1990.

National Coastal Pollution Discharge Inventory. NOAA/NOS. Unpublished data.
Strategic Assessment for Near Coastal Waters, NOAA. (Separate Reports)
     Susceptibility and Status of North Atlantic Estuaries to Nutrient Discharges.
NOAA/U.S. Environmental Protection Agency (U.S. EPA). 1989.
Susceptibility and Status of South Atlantic Estuaries to Nutrient Discharges. NOAA/U.S.
EPA. 1989.
Susceptibility and Status of Gulf of Mexico Estuaries to Nutrient Discharges.
NOAA/U.S. EPA. 1989.
Susceptibility and Status of West Coast Estuaries to Nutrient Discharges. NOAA/U.S.
EPA. 1989.
     National Estuarine Inventory: Physical and Hydrologic Characteristics. NOAA.
Unpublished Data
     Atmospheric Deposition Estimates for Total Nitrogen (1996)
     *Data Source:* National Atmospheric Deposition Program/National Trends Network
(NADP/NTN) at http://nadp.sws.uiuc.edu
     Nitrogen Export (1987)
     *Data Source:* U.S. Geological Survey
     Soil Permeability Index (1998)
     *Data Source:* USDA, 1992. STATSGO - State Soil Geographic Database. Soil
Conservation Service, Publication Number 1492, USDA, Soils Conservation Service,
[National Resource Conservation Service] Washington, D.C.
     Risk of Groundwater Nitrate Contamination by Nitrate (1970-1995)
     *Data Source:* U.S. Geological Survey (USGS)
     Percent of Impaired Waters (1998)
     *Data Source:* U.S. EPA Office of Water (OWOW), Washington, DC


## j.  GIS in Underground Injection Control Inspection Targeting

Hillenbrand, C., W. Hansen, and R. Ferri.  Date unknown.  *GIS in Underground Injection
     Control Inspection Targeting.* U. S. Environmental Protection Agency, Region 2,
     Water Management Division, 26 Federal Plaza, NY, NY 10278. [Online]
     Retrieved 12/09/2003 at
     http://www.epa.gov/region02/gis/projectapps/uicproj.htm.

Summary:
        The Underground Injection Control (UIC) Section, U.S. Environmental Protection
Agency (EPA) Region 2 used a GIS-based risk ranking assessment analysis to identify
the most vulnerable ground water recharge areas by zip code boundary on Long Island,
New York. This risk assessment, using the Region 2 GIS User Interface, is based on a
modified version of the Human Health Risk Index (HRI) technique developed by EPA
Region 6, and can be applied at large spatial extents. Population density, land use, soil,
and travel time to water table data layers are ranked based on population exposure,
degrees of impacts on and vulnerability to an aquifer and the resulting rank layers are
totaled by zip code boundaries to produce risk maps of Long Island, to which UIC
inspectors can be sent to priority areas for further on-site investigation.

This report develops a method that prioritizes aquifer risk at the zip code boundary extent, which could be appropriate at the regional level similar to the rankings of watershed extent investigations such as the Environmental Monitoring and Assessment Program. Readily available data are used, in which current, updated data can be incorporated, easily manipulated and analyzed using current GIS capabilities. This type of approach has potential for application at regional extents, and has potential to incorporate aquifer natural recharge areas for analyzing spatial coincidence with heavily populated zip codes. A raster GIS based analysis could provide more detail as to important areas of aquifer recharge below the spatial extent of the zip code boundaries.

Spatial Extent:
Long Island, New York

Analysis Categories:
SAB category: Chemical and Physical Characteristics

GIS tools:
EPA Region 2 GIS User Interface
ESRI ARC/INFO 6.1.1 software
Population density - 1990 Census TIGER files and STF3a data
Land use data – US Geological Survey's (USGS) Geographic Information Retrieval and Analysis System (GIRAS) 1:250,000 scale dataset using Anderson Level II Land Use - Land Cover classification
Soil permeability data - Soil Conservation Services (SCS) 1:250,000 scale State Soil Geographic Data Base (STATSGO)
1983 water table data - USGS Syosset, New York office
USGS three-arc second elevation data using a 70 meter grid size

### k.   A GIS Based Decision Support System: Eco-Assessor

Davis, A., B. Kleiss, C. O'Hara, and J. Derby.  Date unknown. *The Development of a Decision Support System for Prioritizing Forested Wetland Restoration Areas in the Lower Yazoo River Basin, Mississippi.* [Online] Retrieved  01/05/2004 at http://www.epa.gov/region4/water/specialprojects/yazoo/dssdocument.htm.

Summary:
A GIS based decision support system (DSS) the Eco-Assessor, developed cooperatively between the US Geological Survey (USGS) and EPA, is presented to determine the most suitable locations for forested wetland restoration. The DSS, comprised of a series of ArcInfo AMLs, is loosely based on Hydrogeomorphic Assessment criteria developed by Binson (1993), which evaluate wetlands based on ecological worth, incorporates various spatial data layers grouped for functional ranking by wetland restorability, habitat, water quality, and hydrology. Each functional group is comprised of a data layer in ArcInfo GRID format representing individual wetland functions, such as soil type and frequency of inundation, and is given a rank as to its importance for identifying the most suitable areas for potential restoration. After all

GRIDs are ranked, they are added together, and the GRID cells with highest rankings offer the best potential and location for forested wetland restoration. Following the identification of suitable restoration areas, reforestation scenarios generated using a functional restoration score for each cell, which reflects the economic investment based on area size, and are based on specific wetland functions, or spatial, geographic criteria. The DSS design allows for flexibility in determining the most appropriate functional categories and assigning the respective rankings. The Eco-Assessor also allows for the evaluation of different what-if restoration scenarios optimizing the economic and ecological benefits of the restoration project.

The Eco-Assessor DSS could be modified for identification and preservation of critical forested wetland areas based on the assessment principles drawn from the Hydrogeomorphic Assessment criteria as established by Brinson (1993). The Eco-Assessor is designed to use readily available GIS data, which these methods and data could be geographically transferable to a larger, regional extent provided data are available. Spatially explicit results are output from the Eco Assessor DSS with a resolution of the coarsest data layer. GIS data layers act as surrogates that approximate relative hydrologic wetland functions since the wetlands are not surveyed directly. Through the use of the DSS Eco-Assessor, no new GIS data are created. Functional restoration ranking values for ecological rules are inconsistent within and between function groups. No scientific justification is given for the functional rankings and the weights assigned to the functional groups (hydrology, wetland restorability, water quality and habitat)

More information is available in *A DECISION SUPPORT SYSTEM FOR PRIORITIZING FORESTED WETLAND RESTORATION IN THE YAZOO BACKWATER AREA, MISSISSIPPI by Charles G. O'Hara, Angela A. Davis, and Barbara A. Kleiss, U.S. Geological Survey Water-Resources Investigations Report 00—4199.*

Spatial Extent:
Six county extent in the Yazoo backwater area in central western Mississippi; has potential application at a regional extent incorporating both riparian, island, and backwater wetlands.

Analysis Categories:
SAB categories: Chemical and Physical Characteristics, Hydrology and Geomorphology, Biotic Condition (subcategory Ecosystems and Communities), Landscape Condition, and Natural Disturbance Regimes

GIS tools:
Eco-Assessor Decision Support System (comprised of multiple ArcInfo AMLs and menu tools)
25m x 25m raster resolution for all data layers
Universal Transverse Mercator, Zone 15 (UTM 15) projection, North American Datum of 1927 (NAD 27)
1988 Land use/land cover generated from Landsat satellite imagery purchased by the United States Army Corps of Engineers) USACE

Flood image data from 1988 Landsat satellite imagery data provided by USACE

Hydric soils data provided by USACE and National Resource Conservation Service (NRCS)

Geomorphology data compiled at 1:250,000 scale provided by Saucier (1994)

Public lands data provided by US Fish and Wildlife Service (USFWS)

Roads and transportation data (primary and secondary roads) at 1:100,000 scale provided by Mississippi Automated Resources Information System (MARIS)

Permanent water bodies provided by MARIS

Hypsographic elevation contour data provided by MARIS compiled from United States Geologic Survey (USGS) 1:24,000 7.5 minute topographic map series

Hydrologic data network as River Reach File Level 3 (RF3) provided by Environmental Protection Agency (EPA)

Farmed wetlands, areas with a 50% chance of flooded/ponded for 15 consecutive days or more during the growing season, provided by NRCS

Digital elevation data derived from high-resolution hypsographic (MARIS) and interpolated to 10 m raster cell resolution

1:24,000 USGS 7.5 minute topographic series base maps

References:

Brinson, M.M. 1993. A hydrogeomorphic classification for wetlands. WRP-DE-4. Vicksburg, MS: U.S. Army Corp of Engineers, Waterways Experiment Station.

## l.  Proposed Sediment Total Maximum Daily Load (TMDL) Development, Mississippi

U. S. Environmental Protection Agency, Region 4. 2002. *Proposed Sediment Total Maximum Daily Load (TMDL) Development, James Creek (HUCs 03170009), Upper Tombigbee River Basin, Mississippi*. [Online] Retrieved  01/05/2004 at http://www.epa.gov/Region4/water/tmdl/mississippi/tombigbee/jamescreek_proposed_tmdl.pdf.

Summary:

Total maximum daily loads (TMDLs) for sediments are developed for the James Creek watershed of the Upper Tombigbee River Basin, northeast Mississippi. James Creek has impaired biological assemblages due to sedimentation as indicated by filed observations. These TMDLs will be used to determine the appropriate sediment loading to James Creek based on TMDL development for a biologically unimpaired stream, Spring Creek, in the same ecoregion as James Creek. The TMDLs will be developed using the Sediment Tool extension, based on the Universal Soil Loss Equation (USLE) that predicts average annual soil loss caused by erosion, of the EPA's Watershed Characterization System (WCS). The Sediment Tool simulates, in a mechanistic manner, runoff and sediment delivery using precipitation as input whereby solid loads generated by runoff are used to estimate pollutant delivery based on sediment deposition. The existing sediment load to James Creek is 0.7 tons per year per acre with a target sediment load of 0.4 tons per year per acre, a 40% reduction in sediment yield, with historic and current agricultural activities,

urbanization, stream channelization, and highway and road construction identified as the main causes for sedimentation.

WCS is available currently for Region 4 only with plans for future accessibility to other regions. Some input data are available with the WCS download package and website on an 11 digit HUC watershed extent but could be accessed also from the original data vendors. The USLE approach is scientifically sound and has been developed for the continental US therefore has potential applicability outside of region 4. The development of sediment TMDLs for a watershed can be geographically transferable dependent on the availability of input GIS data and a reasonable watershed size for field investigation. This TMDL application is conducted at a large scale watershed approximately 27,000 acres and could be scaled easily upward for larger watersheds possibly at the regional extent. Regardless of the spatially explicit input data the results of TMDL development are generalized, reported at the watershed level, in nature providing a target threshold below which it is necessary to maintain necessary biological condition of a stream. A watershed could be disaggregated further to provide more spatial indication of TMDL target thresholds. Point sources of direct contributions to sedimentation were not considered explicitly but non point sources of sedimentation were using the USLE embedded in the Sediment Tool.

Extent:
The James Creek 27,380 acre watershed in northeast Mississippi.

Categories of Analysis:
This investigation addresses the SAB category of analysis, Hydrology and Geomorphology and its subcategory of Sediment and Material Transport.

GIS Tools:
Detailed landuse distribution is based on the Multi-Resolution Land Characteristics (MRLC) derived from Landsat TM imagery acquired in 1992.
USGS 30m by 30m digital elevation model (DEM)
US Census TIGER Roads
STATSGO 1:250,000 soil data
EPA ArcView-GIS based WCS v2 Sediment Tool (http://wcs.tetratech-ffx.com/).
USGS 11 Digit HUC watersheds
EPA RF3 1:100,000 stream network

## m.  Total Maximum Daily Load (TMDL) Development, Florida

U.S. Environmental Protection Agency, Region 4. Date unknown. *Proposed Total Maximum Daily Load Development For the Northern and Central Indian River Lagoon and Banana River Lagoon, Florida: Nutrients, Chlorophyll a and Dissolved Oxygen.* [Online] Retrieved 01/05/2004 at http://www.epa.gov/Region4/water/tmdl/florida/indian_river/IRL TMDL-Proposed.pdf.

Summary:

Seventeen segments of the Indian River Lagoon basin are identified on the Florida Department of Environmental Protection (DEP) 1998 303(d) list as impaired by nutrients, dissolved oxygen, or chlorophyll. Additionally, the Indian River Lagoon Surface Water Improvement Management (SWIM) Plan proposes "to attain and maintain water and sediment of sufficient quality … in order to support a healthy, macrophyte-based estuarine lagoon system and ecosystem which supports endangered and threatened species, fisheries and wildlife." The Pollutant Load Screening Model (PLSM) developed by the St Johns River Water Management District (SJRWMD) is a spatially distributed GIS-based storm water model that can estimate the annual load per acre for each individual drainage basin of total nitrogen, total phosphorus, and total suspended solids delivered to the North and Central Indian River Lagoon and Banana River Lagoon (N&CIRL& BRL), along the east coast of Florida.

Point sources of permitted nutrients loads from municipal wastewater facilities and Separate Storm Sewers are incorporated in the wasteload allocation of the TMDL. Landuse distribution in and around the basin supply nonpoint sources of nutrient loadings in the form of dead plant matter, fertilizers, and atmospheric deposition that is washed from the land surface into the adjacent water bodies. To operationalize the model twenty five years of mean annual rainfall (1930-1954) are used as input into the PLSM to produce the average annual loading rate since seagrass is the critical resource under investigation, which grows throughout the year. Seasonally variation of nutrient loading is investigated by calculating wet season nutrient loads based on measured flow and average nutrient concentrations in those discharges over a 4 year period (1996-1999). Water quality data from the Florida Department of Environmental Protection (FDEP) and the SJRWMD with additional data from Florida Environmental Data Extraction Tool (FEDET) (http://fedet.tetratech-ffx.com/fedet/index.jsp) are used to verify the PLSM. Additional parameters from soils, landuse, hydrologic boundaries, and runoff coefficients are also needed for the PLSM. Additional layers include the Soil Survey Geographic Database (SSURGO), SJRWMD 1995 FLUCCS land use, and USGS 7 ½ minute hydrologic boundaries. Model parameters include runoff coefficients from SJRWMD based on soil and land use types, and coefficients for nutrient concentrations based on landuse types.

The PLSM model was calibrated against measured pollutant loads whereby it under predicted flow, slightly over predicted total nitrogen and total phosphorus, and over predicted total suspended solids load. Point sources did not contribute greatly to loadings as did non point sources, which show considerable variability in total nitrogen and phosphorus loads and loading rates per acre throughout the watershed area. The derived TMDLs (in lbs/yr) for nitrogen and phosphorus, comprised of the sum of individual wasteload allocations for point sources from NPDES permitted facilities, and load allocations for both nonpoint sources and natural background levels based on the PLSM results, provide thresholds for future water quality restoration for individual segments and the watershed as a whole.

Identification of ecologically sensitive stream reaches can be identified in a timely fashion with commonly available data. The software needs (GIS and RDBMS) are reasonable and can be employed readily and easily in any EPA regional office. The PLSM model has precedent for yielding reasonable results, has good user documentation,

and could be applied in any EPA region at any spatial extent. The data used by the model are readily available at the national level, which is viable for subsetting to the regional extent. The model runs in a raster based GIS environment but the results are determined on a per stream segment basis The input data, model, and results are spatially explicit, dependent on the data layer with the largest grain resolution.

Extent:
Northern and Central Indian River Lagoon and
Banana River Lagoon, Florida (2,284 square miles)

Categories of Analysis:
This application addresses the SAB categories of Chemical and Physical Characteristics and the subcategories, Nutrient Concentrations (Nitrogen and Phosphorus) and Other Chemical Parameters (Dissolved Oxygen).

GIS Tools:
Pollutant Load Screening Model (PLSM)
SSURGO soils data
SJRWMD 1995 FLUCCS land use
USGS 1:24,000 7 ½ minute hydrologic boundaries

### n. South Florida Ecosystem Assessment: Phase I/II

U. S. Environmental Protection Agency, Region 4 Science & Ecosystem Support Division. 2001. *South Florida Ecosystem Assessment: Phase I/II (Summary) – Everglades Stressor Interactions: Hydropatterns, Eutrophication, Habitat Alteration, and Mercury Contamination.* Monitoring for Adaptive Management: Implications for Ecosystem Restoration. Water Management Division and Office of Research and Development. EPA 904-R-01-002. Online: http://www.epa.gov/region4/sesd/reports/epa904r01002.html accessed on 01/05/2004.

Summary:
With the goal of scientifically sound management decisions for the Everglades ecosystem and its restoration, the United States Environmental Protection Agency (US EPA) Region 4 South Florida Ecosystem Assessment Project covers long-term research, monitoring, and assessment of ecosystem condition and trends, and risks of environmental stressors from hydropattern modification, habitat alteration, eutrophication, phosphorus loading, and mercury contamination acting on the Everglades ecosystem. This report summarizes the results of previous Everglades marsh and canal sampling that assesses hydropattern (referring to the depth, duration of flooding, timing, and distribution of freshwater flows in the Everglades) modification during the wet and dry seasons; plant community responses and habitat alteration resulting from nutrient loadings and hydropattern alteration; and the current status, potential sources of, and mechanisms controlling mercury contamination. The relative risks from and interactions

of these stressors, and current and future management implications of the Everglades ecosystem are covered also.

Samples of surface water, soil, fish, and algae representing 750 marsh and 200 canal locations were collected from 1993 to 1999 from south of Lake Okeechobee to the mangrove fringe on Florida Bay and from the urban, eastern coast to Big Cypress National Preserve on the west. Additional data include periphyton and macrophyte species, plant tissues, and plant community delineations from ground sampling and aerial photo interpretation. Sampling sites locations are selected using a statistical, probability based sampling strategy to provide statistical confidence in inferential analyses and to eliminate sampling bias. Using Kriging interpolation surfaces are created representing the spatial distributions of many of the sampling variables for each sampling period.

Each of the separate areas comprising the Everglades is identified and spatial trends and hotspots discussed when referring to the interpolated surfaces of the respective sampling variables. Surfaces of water depth are created to assess the hydropatterns during the wet and dry seasons, which varies from about 45% to 100% coverage of the 5500 sq km study area. Using GIS methods (specifics are unknown) the spatial extent of surface water coupled with the water depth measurements are used to derive a surface water volume to surface area curve for the ecosystem, along with area measurements and contours of long to short hydropatterns. Characterization of existing plant communities to assess habitat condition and alteration is investigated by vegetation mapping using aerial photo interpretation, classification of macrophyte species, and relating plant morphological changes to abiotic spatial changes. Various plant communities are mapped based on occurrence at each sampling location and are related to hydropattern characteristics and nutrient loadings. interpolated Surfaces are generated for wet and dry seasons for total phosphorus and nitrogen in surface water and soil, total mercury in soil, total organic carbon in surface water, sulfate in surface water, and sulfide in surface and pore waters. These maps show a general north-south gradient of concentrations. Stormwater Treatment Areas and agricultural Best Management Practices will be used to control nutrient enrichment into the Everglades from the Everglades Agricultural Area. Subsidence by peat loss is shown by interpolated surfaces.

This project represents a comprehensive, and intensive sampling effort to monitor, assess, and plan for a regional extent wetland ecosystem. Regardless of the South Florida Everglades geographic focus, these sampling methods, and analysis techniques (aspatial and spatial statistics) could be applied to other extensive wetland or estuarine ecosystems in any EPA region. There is some presumption that other extensive regional wetland and/or estuarine ecosystems suffer from similar stressors of hydropattern modification, habitat alteration, nutrient and mercury loadings, and eutrophication as the Everglades. Following this report, previous interim and technical reports, a regional extent ecosystem investigation could be undertaken with similar goals (modified to be location specific, of course), sampling strategies, and analysis methods. The sampling covered the entire Everglades ecosystem in a thorough and well-dispersed manner capturing key controls (marshes and canals) on the ecosystem functioning. This study could be adapted to an investigative approach for identifying critical habitats for preservation based on the key indicator variables measured (indicator species and chemical indicators for water quality). The only critique is that further spatial analysis was not performed on the spatial maps produced from the Kriging interpolation. A more robust spatial analysis involving

raster map algebra could be a key approach of better understanding spatial patterns of wetland, estuarine health/integrity and identify hotspots of impacted ecosystem highlighted by the spatial coincidence of two or more indicator variables.

Extent:
South Florida Everglades ecosystem covering 5,500 km$^2$

Categories of Analysis:
The following SAB reporting categories of analysis are addressed:
Landscape Condition – All subcategories
Biotic Condition – Ecosystems and Communities (Community Extent, Community Composition); Species and Population (Population size); Organism Condition (Physiological Status)
Chemical and Physical Characteristics  – Nutrient Concentrations (All subcategories); Trace Inorganic and Organic Chemicals (Metals, Organic Compounds); Other Chemical Parameters (Dissolved Oxygen)
Ecological Processes – Material Flow (All subcategories)
Hydrology and Geomorphology – Surface and Groundwater Flows (Pattern of Surface Flows, Hydrodynamics);

GIS Tools:
SURFER 9 (Golden Software 1999) and ARCVIEW (1996) for Kriging surface interpolation, and surface water volume calculations map creation, respectively. Trimble Pathfinder Pro GPS.
Sampling data in DBASE III format available online for download (http://www.epa.gov/region4/sesd/reports/epa904r98002/sf1data.html and http://www.epa.gov/region4/sesd/reports/epa904r01003/app-d.html )

**o.  Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)**

U. S. Environmental Protection Agency. Date unknown. *Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)*. [Online] Retrieved 12/09/2004 at http://www.epa.gov/waterscience/BASINS/.

Summary:
        Five water quality models are available from EPA (http://www.epa.gov/waterscience/wqm/) for dynamically simulating movement of precipitation and pollution for natural and urban drainage pathways in both single event and continuous simulation modes. EPA supported water quality models include BASINS, QUAL2E, AQUATOX, CORMIX, WASP6, and the EPA Center for Exposure Assessment Modeling (CEAM), These models are used to assess potential impacts of point and non-point source pollution (BASINS, QUAL2E and CORMIX); fate and transport of solutes and their effects on aquatic ecosystems (AQUATOX); and for developing total maximum daily loads (TMDLS) (QUAL2E). A review is given of BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) and the respective submodels necessary for dynamic analysis of the fate and transport of solutes

in a hydrologic system. This software suite readily incorporates vector GIS data for the dynamic simulation of solute transport in spatially aggregated watersheds or subwatersheds.

BASINS is a multipurpose environmental analysis system at multiple spatial extents for performing watershed and water quality based studies at selected stream sites or throughout an entire watershed" to assess potential impacts of point and non-point source pollution. The initial and current premise of BASINS is to allow the examination of environmental information, to provide an integrated watershed and modeling framework, and to support analysis of point and nonpoint source management alternatives. Methods for assessing total maximum daily loads (TMDLs) for a stream can be developed using both point and nonpoint source pollution capabilities of BASINS. Some of the multipurpose functionality of BASINS includes assessing protection of source drinking water, and storm water management. Availability from EPA is unrestricted and documentation is provided describing the installation and operation of each model. Three spatially averaged dynamic simulation models are included within BASINS. HSPF and SWAT are watershed pollutant loading and solute transport models; and PLOAD, is a simplified GIS based nonpoint source annual pollutant loading model. QUAL2E, an one dimensional water quality model that can simulate the fate and transport under given flow conditions and can be used for developing total maximum daily loads. Currently, BASINS is supported as a suite of extensions for ESRI's ArcView 3.x GIS software. Subsequent release versions after BASINS3.1 (2004) will be compatible with ArcGIS and will use the ArcHydro data model.

Spatial Extent:
National extent subdivided into 8-digit HUC watersheds (scale of 1:250,000).

SAB Reporting Categories:
Chemical and Physical Characteristics (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Surface and Groundwater Flows)

GIS Tools:
*GIS datasets distributed with BASINS:*
http://www.epa.gov/waterscience/basins/metadata.htm.
Spatially Distributed Data
1:250,000 Scale Quadrangles of Landuse/Landcover GIRAS Spatial Data of Conterminous United States (CONUS) in BASINS (ArcView Shapefile format)
1990 TIGER Urbanized Areas/Polygons for CONUS, Alaska, and Hawaii in BASINS scale: 1:24,000 (ArcView shape file format)
USEPA Populated Place Point Locations for CONUS, Alaska, and Hawaii in BASINS (ArcView shape file format)
U.S. EPA Reach File 1 (RF1) for the Conterminous United States in BASINS 1:250,000 (ArcView shapefile and associated dbf)
National Cooperative Soil Survey State (NRCS) Soil Geographic (STATSGO) Database for CONUS, Alaska, and Hawaii in BASINS (1- by 2-degree topographic quadrangle units) (ARCVIEW Shapefile Format)

USGS 300 Meter Resolution, 1-Degree Digital Elevation Models (DEM) for CONUS, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands (ArcView shape file format)
National Highway Planning Network DOT/FHA Major Roads for CONUS, Alaska, and Hawaii in BASINS 1:100,000 scale (ArcView shape file format)
U.S. Geological Survey  Hydrologic Unit Boundaries of the Conterminous United States in BASINS, 1:250,000-scale (ArcView shape file format)
U.S. Environmental Protection Agency/Office of Water/OST National Inventory of Dams in BASINS (ArcView shape file format)
USEPA Regional Boundaries in the United States for BASINS 1:2,000,000-scale (ArcView shape file format)
U.S. Environmental Protection Agency/Office of Water/OST State Boundaries in the United States for BASINS 1:2,000,000-scale (ArcView shape file format)
U.S. Environmental Protection Agency/Office of Water/OST Counties and County Equivalents Boundaries in the United States for BASINS 1:2,000,000-scale (ArcView shape file format)
U.S. Environmental Protection Agency/Office of Water/OST Federal, State, Tribal, or Local Government Managed Areas for CONUS in BASINS 1:2,000,000-scale (ArcView shape file format)
U.S. Environmental Protection Agency/Office of Water/OST Level III Ecoregions of the Conterminous United States in BASINS from USGS 1:250,000 base maps (ArcView shape file format)

Environmental Monitoring Data

EPA's STORET Water Quality Monitoring and Data Summaries for CONUS (ArcView shapefile and associated dbf)
EPA's STORET Water Quality Observation Data for CONUS (ArcView shapefile and associated dbf)
EPA's STORET Bacteria Monitoring Stations and Data Summaries for CONUS (ArcView shapefile and associated dbf)
NOAA's National Climatic Data Centers (NCDC) Weather Data Management (WDM) Stations Point Locations in the United States, Puerto Rico, and the U.S. Virgin Islands (ArcView shapefile and associated dbf)
USEPA STORET Stream Flow Data from Gauging Stations in CONUS (ArcView shapefile and associated dbf)
1996 National Listing of Fish Consumption Advisories for the United States (DBASE File format)
USEPA National Sediment Inventory (NSI) Version 1.2 for the Conterminous U.S. (ArcView shapefile and associated dbf)
1996 EPA/OW Clean Water Needs Survey (CWNS) for the United States and U.S. Territories

Point Source Data

EPA Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) or Superfund for the United States (ArcView shapefile and associated dbf)

EPA/OW Permit Compliance System for BASINS Version 3 in CONUS (ArcView shapefile and associated dbf)
EPA/OW Permit Compliance System for CONUS (ArcView shapefile and associated dbf)
USEPA Toxic Release Inventory Facilities in the United States (ArcView shapefile and associated dbf)
EPA/OW Industrial Facilities Discharge Database for CONUS (ArcView point shapefile)
EPA/OSW Resource Conservation and Recovery Information System (RCRIS) for the United States (ArcView shapefile and associated dbf)
USBM Mineral Availability System (MAS)/Mineral Industry Location in CONUS (ArcView shapefile)

## p. Water Quality Analysis Simulation Program (WASP) Version 6.0

Wool, T.A., R.B. Ambrose, J.L. Martin, and E.A. Comer.  Date unknown.  *Water Quality Analysis Simulation Program (WASP) Version 6.0 Draft: User's Manual.* U.S. Environmental Protection Agency – Region 4. Atlanta, GA. [Online] Retrieved 12/15/2003 at http://www.epa.gov/athens/wwqtsc/html/wasp.html.

Summary:
WASP6, an enhanced Windows version of the EPA Water Quality Analysis Simulation Program (WASP), is a dynamic, computer based component model that simulates the processes of advection, dispersion, point and diffuse mass loading, and boundary exchange in one, two, and three dimensional water aquatic systems, and allows users to interpret and predict water quality responses to natural and human induced point and non-point source pollutants. WASP6 allows a user to preprocess input data into the WASP required format, and contains eutrophication and organic chemical model processors, and a graphical post-processor for the viewing of results and comparison to observed field data. WASP consists of two models for the modeling of toxic pollutants (involving organic chemicals, metals, and sediment) and the assessment of conventional pollutants (involving dissolved oxygen, biochemical oxygen demand, nutrients and eutrophication) through two stand-alone computer programs DYNHYD5, which simulates water movement, and WASP6 for the movement and interaction of pollutants within the water. Both programs operate on the principle of the conservation of mass whereby water volume and water-quality constituent masses are monitored and accounted for over time and space during the simulations. DYNHYD5 also accounts for the conservation of energy during hydrodynamic routing of water. Increasing current functionality WASP6 also can be linked with hydrodynamic and sediment transport models to model flows, depths velocities, temperature, salinity, and sediment fluxes.
Previous applications of WASP6 include the assessment of eutrophication in Tampa Bay, the Potomac Estuary, the Neuse River and estuary, and the Great Lakes; and for investigating phosphorus loading to Lake Okeechobee. WASP6 could be used to monitor conventional and toxic pollutants within a water body to establish total daily maximum loads (TMDLs), and identify those areas within the water body that are important for conservation. Continued monitoring would provide a baseline for the protection of these aquatic resources, and would identify the need for remediation

measures if the pollutants exceed the recommended TMDLs. SAB reporting categories that could be addressed by using WASP6 include Chemical and Physical Characteristics (all subcategories); Ecological Processes (Material Flow); and Hydrology and Geomorphology (Surface and Groundwater Flows, and Sediment and Material Transport). For more information see the following URL:
http://www.epa.gov/athens/wwqtsc/html/wasp.html

Spatial Extent:
Medium to large sized open water bodies and estuaries.

SAB Reporting Categories:
Chemical and Physical Characteristics  (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Surface and Groundwater Flows)

GIS Tools:
EPA Water Quality Analysis Simulation Program (WASP),

## q.  Automated Geospatial Watershed Assessment (AGWA)

Miller, S.N., D.J. Semmens, R.C. Miller, M. Hernandez, P. Miller, D.C. Goodrich, W.G. Kepner and D.W. Ebert. 2002. *Automated Geospatial Watershed Assessment (AGWA) - A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual - Version 1.3.* U.S. Environmental Protection Agency. EPA/600/R-02/046. ARS/137460. [Online] Retrieved 05/27/2004 at http://www.epa.gov/nerlesd1/land-sci/agwa/index.htm.

Summary:
The Automated Geospatial Watershed Assessment (AGWA) tool is a GIS-based multipurpose hydrologic analysis system developed by U.S. EPA Office of Research and Development in conjunction with the USDA-ARS Southwest Watershed Research Center for use in performing watershed- and basin- scale studies and to support landscape assessment at multiple spatial and temporal scales. AGWA is an extension for ESRI's ArcView 3.2 that uses readily available GIS data sets obtained through the Internet to parameterize and run two spatially distributed watershed runoff and erosion models, Soil Water Assessment Tool (SWAT), and Kinematic Runoff and Erosion Model (KINEROS).
Using digital data in combination with the automated functionality of AGWA greatly reduces the time required to prepare input data for SWAT and KINEROS. Using a digital elevation model a watershed is delineated from a user-specified outlet, and sub-basins and stream channel reaches created. Hydrologic properties for land cover and soils data are also extracted using the watershed, sub-basins, and channel data layers. Spatially uniform or distributed precipitation surfaces can be created in slightly different input formats for  both models using gauge locations and Theissen polygon interpolation. Once all input parameters are generated, the models are run for  runoff and erosion simulations.

Results from model simulations can be displayed visually for sub-basins and channels, with all necessary components of the land based water balance.

AGWA was designed to evaluate likely out-comes of management scenarios and rank different areas in a watershed in terms of likely consequences to change. It also is designed to perform watershed analyses over large areas such as entire basins, making it ideal for regional scale ecosystem assessments using watersheds as a unit of investigation. Model results are displayed in tabular format allowing managers to identify critical areas needing management activities and to anticipate sensitive and critical ecosystem areas for planning allowances. AGWA provides qualitative estimates of water runoff and erosion for a watershed, and has been tested in geographically diverse watersheds across the continental United States. The AGWA tool can use many readily available GIS data layers (coverages, shapefiles, and grids) from the Internet that are easily input into ArcView. The data types and their vendors are listed below.

SAB Reporting Categories:
Chemical and Physical Characteristics (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Surface and Groundwater Flows)

Spatial Extent:
Applicable for small watersheds (less than 100 km2) for SWAT model, and large watersheds (about 1000 km2) for KINEROS model.

GIS Tools:

Watershed Delineation

USGS Digital Elevation Model (DEM)
http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html
http://edc.usgs.gov/webglis
http://edcsns17.cr.usgs.gov/EarthExplorer/

Land Cover and Soils Parameterization

North American Land Cover Characterization (NALC)
http://eosims.cr.usgs.gov:5725/CAMPAIGN_DOCS/nalc_proj_camp.html
Multi-Resolution Land Characteristics (MRLC) Consortium - National Land Cover Data (NLCD) http://www.epa.gov/mrlc/nlcd.html
New York - state-specific classification scheme
http://www.epa.gov/owow/watershed/landcover/lulcny.html
State Soil Geographic Database (STATSGO) soils coverage/shapefile
http://www.ftw.nrcs.usda.gov/stat_data.html

KINEROS and SWAT Precipitation Data

National Weather Service
NOAA Atlas 2 http://www.nws.noaa.gov/oh/hdsc/noaaatlas2.htm
National Climatic Data Center http://www.ncdc.noaa.gov/
Western Regional Center http://www.wrcc.sage.dri.edu

**r. Watershed Assessment, Tracking & Environmental Results (WATERS)**

U. S. Environmental Protection Agency. Date Unknown. *Watershed Assessment, Tracking & Environmental Results (WATERS)*. [Online] Retrieved 01/29/2004 at http://www.epa.gov/waters/about/index.html.

Summary:

WATERS is a unified data repository from several previously unconnected databases of water quality data for public interest and concerns about watershed health and the safety and condition of drinking water. A more detailed summary is provided at this website about the premise, data structure, components and goals of WATERS in addition to a listing of the tools and data that comprise WATERS. The data used are based on the National Hydrography Dataset developed by the USGS. These data provide a common link between EPA water quality data and the spatial data whereby a relational type of data structure is established.

The 303(d) Listed Impaired Waters data sets (points, lines, and polygons) are geographically distributed throughout the continental US but are not continuous in spatial coverage. Relational tables for water impairments and TMDLs are provided for the 303(d) Listed Impaired Waters data set. The 305(b) Water Quality Assessments and Water Quality Standards data sets are not readily accessible by web therefore require correspondence with an EPA contact for acquisition. Relational tables of water quality and designated use assessments, impairments and potential source of impairments are available directly from the web for the 305(b) Water Quality Assessments data set. Status for spatial completeness is given by data set type and is current as of September 18, 2002. The data can be found at the following URL:
http://www.epa.gov/waters/data/downloads.html.

Spatial Extent:
National extent subdivided into 8-digit HUC watersheds (scale of 1:250,000).

SAB Reporting Categories:

Chemical and Physical Characteristics (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations)

GIS Tools:

USEPA 1:100,000 scale Reach File version 3 (RF3) vector data format.

**2) U.S. Geological Survey- Gap Analysis Program (GAP) and other data advances**

**a. Gap Analysis Program (GAP)**

U.S. Geological Survey. 2003. *Gap Analysis Program History and Overview.* [Online]
      Retrieved May 5, 2004 at
      http://www.nbii.gov/about/pubs/factsheet/pdf/gap_fs.pdf.

U.S. Geological Survey. 2003. *National Gap Analysis Program.* [Online] Retrieved
      May 5, 2004 at http://www.gap.uidaho.edu/.

      The U.S. Geological Survey Gap Analysis Program (GAP) is a nationwide
program that develops geographically explicit information on the distribution of native
vertebrate species, their habitat preferences, and their management status. "Gap analysis"
is a scientific method for identifying the degree to which native plants and animals are
represented in current conservation networks. In order to develop state and region-wide
natural communities and species maps, GAP uses satellite imagery, air video, field data,
and expert knowledge. Predictive modeling is employed to map species to predict their
distributions based on mapped habitat characteristics. GAP data is available on
CD_ROM or on the GAP website (http://www.gap.uidaho.edu/). The following data is
available: land cover maps produced from 30-meter satellite imagery showing dominant
vegetation types (digital GIS format); species distribution maps that depict the predicted
distribution of each vertebrate species (digital GIS format); land stewardship maps that
indicate categories of ownership, managing authority, and management status for
biodiversity conservation (digital GIS format); and state project reports that offer
analyses of the conservation status for each species and natural community (digital form
with graphic versions of all GIS maps).

**b. National Hydrography Dataset (NHD)**

U. S. Geological Survey. 2000. *National Hydrography Dataset (NHD) USGS*. [Online]
      Retrieved 01/29/2004 at http://nhd.usgs.gov/index.html.

Summary:
      The NHD is a digital spatial database consisting of surface water features
including surface water features such as lakes, ponds, streams, rivers, springs and wells.
Information is included about naturally occurring and constructed bodies of water, paths
through which water flows, and other related hydrologic features. These data are based
on the USGS 1:100,000 scale Digital Line Graph (DLG) data format incorporated with
the Reach File version 3 (RF3) from the EPA expanding and refining their individual
characteristics for state, regional, and national extent water quality and hydrologic
analyses. Features represent bodies of water, paths through which water flows, and
related hydrographic entities. Reaches, composed of one or more features, are segments
of surface water with similar hydrologic characteristics. Flow relationships link together
individual transport and coastline reaches to form the surface water drainage network. A

geographic name provides a proper name, specific term, or expression by which a particular feature or reach is known. Additionally, a ten-digit integer value uniquely identifies each feature or reach. The horizontal coordinates are latitude and longitude values with the horizontal datum of North American Datum of 1983. Lengths and areas of features and reaches, computed from a projected coordinate system, are supplied for convenience, and surface elevations and the associated stage where water pools are supplied for some features. Applications using the NHD data include the following: map production using the positional and descriptive data of the NHD, geocoding observations by linking descriptive and positional data to water features, modeling the flow of water using information about flow direction, and material transport (chemicals, pollutants and sediment) in the stream network, and the maintenance of data by organizations through the sharing of cost of improvements and updating facilitated by unique numerical identifiers for each hydrologic feature within the NHD.

Spatial Extent:
National extent subdivided into 8-digit HUC watersheds (scale of 1:250,000).

SAB Reporting Categories:
Hydrology and Geomorphology (Dynamic Structural Characteristics, Surface and Groundwater Flows)

GIS Tools:
ESRI's ArcInfo vector coverage data format.

## 3) The Nature Conservancy- Ecoregional Planning

Groves C., L. Valutis, D. Vosick, B. Neely, K. Wheaton, J. Touval, and B. Runnels. 2000. *Designing Geography of Hope: A Practitioner's Handbook to Ecoregional Conservation Planning, Second Edition, Volume I.* The Nature Conservancy. [Online] Retrieved May 5, 2004 at http://www.conserveonline.org.

Groves C., L. Valutis, D. Vosick, B. Neely, K. Wheaton, J. Touval, and B. Runnels. 2000. *Designing Geography of Hope: A Practitioner's Handbook to Ecoregional Conservation Planning, Second Edition, Volume II.* The Nature Conservancy. [Online] Retrieved May 5, 2004 at http://www.conserveonline.org.

The Nature Conservancy, Northern Tallgrass Prairie Ecoregional Planning Team. 1998. *Ecoregional planning in the Northern Tallgrass Prairie ecoregion.* The Nature Conservancy, Midwest Regional Office, Minneapolis, MN, USA. 208 pp.+ iv.

The Nature Conservancy uses ecoregional planning to set conservation priorities. Ecoregions are delineated by Robert Bailey's U.S. Forest Service ECOMAP.  An ecoregional plan will be developed by The Nature Conservancy for each ecoregion of the nation. Ecoregions are broad land areas defined by geology, topography, climate, and vegetation.  Ecoregional planning is used to target the species, communities and ecosystems that represent an ecoregion's biodiversity.  In developing an ecoregional plan,

a list of conservation targets is compiled.  Natural Heritage Program element occurrence data, expert input, and Rapid Ecological Assessments are used to map and display the distribution of species and natural communities targets.  Biophysical or environmental analyses are combined with land cover type data and satellite imagery to predict locations of ecological systems when such information is lacking.  Biophysical or environmental analyses may be completed by deriving data from readily available digital spatial data sets such as digital elevation models (DEMs), surficial geology, and hydrography.  Once the locations of conservation targets are determined, potential conservation sites may be identified.  The size of conservation sites is determined by the habitat needs of targets located within them.  Small sites are delineated by Heritage data, while larger sites are delineated by satellite Thematic Mapper imagery with a ground resolution of 30 meters.  Identified conservation sites are compiled in GIS coverages.  The viability of conservation sites is then examined using condition, size, and ecological context as criteria.  Data layers depicting roads, population density, and land use conversion are obtained or developed.  Site selection may then be aided by using GIS-based suitability indices in combination with computer algorithms such as SITES, which has been developed specifically for ecoregional planning purposes.  SITES is available on CD-ROM from The Nature Conservancy Boise Conservation Planning Office.  Areas managed for conservation purposes are also compiled into coverages, and managed area boundary data is obtained from the following sources: Natural Heritage Programs, Nature Conservancy Field Offices, U.S. Geological Survey GAP Programs, U.S. Forest Service and Research Natural Area programs, National Park Service, Bureau of Land Management, Natural Resource Conservation Service, Fish and Game departments, State Land Boards, State Parks, Land Trusts, and County Open Space and Parks departments.  The conservation site coverages and managed area coverages are then compared.

## 4)  NatureServe Data

NatureServe.  2003.  *NatureServe.*  [Online] Retrieved May 7, 2004 at
      http://www.natureserve.org/.
NatureServe.  2003.  *NatureServe Explorer.*  [Online] Retrieved May 7, 2004 at
      http://www.natureserve.org/explorer/.

NatureServe is a non-profit organization that provides scientific information and tools to aid conservation efforts.  It operates a network of 74 Natural Heritage Programs and conservation data centers, which provide detailed local information about rare and endangered species and threatened ecosystems in all 50 U.S. states, Canada, Latin America, and the Caribbean.  NatureServe provides data for more than 55,000 species and ecosystems on its website, NatureServe Explorer (http://www.natureserve.org/explorer/.  A comprehensive report is available on the NatureServe Explorer website for each species and includes information in the following categories: classification, conservation status, status rank factors, distribution, ecological and life history, economic attributes, management summary, authors and contributors, and references.  Detailed range maps for all birds and mammals that occur in both North America and Latin America may be obtained from NatureServe Explorer.  Maps for birds indicate the following information: migratory or resident status, historic versus current ranges, and native or introduced status.  Migratory status data indicates where birds are permanent residents, breeding residents, non-breeding residents, or passage migrants.

Maps for mammals indicate the following information: historic versus current ranges, native or introduced status, and island distributions, where applicable. NatureServe is headquartered in Arlington, Virginia, with field offices in four U.S. locations and in Canada.


## 5) Florida Assessments

### a. Florida Fish and Wildlife Conservation Commission's Closing the Gaps and Habitat Conservation Needs Report

Cox, J., R. Kautz, M. MacLaughlin, and T. Gilbert. 1994. *Closing the gaps in Florida's wildlife habitat conservation system: recommendations to meet minimum conservation goals for declining wildlife species and rare plant and animal communities*. Florida Game and Fresh Water Fish Commission, Tallahassee Florida.

Cox, J., and R. Kautz. 2000. *Habitat conservation needs of rare and imperiled wildlife in Florida*. Office of Environmental Services, Florida Fish and Wildlife Conservation Commission, Tallahassee, Florida.

Kautz, R., and J. Cox. 2001. *Strategic habitats for biodiversity conservation in Florida*. Conservation Biology 15:55-77.

The Florida Fish and Wildlife Conservation Commission developed ground-breaking GIS assessments of habitat needed to protect viable populations of many species of conservation interest. The assessments included moderately detailed landcover classifications derived from LandSat imagery, occurrence data for some species, existing conservation lands data, and coarse population viability models to determine how much habitat was needed to protect viable populations and what was the best available habitat to protect if additional protection was needed.

### b. Florida Ecological Greenways Network

Hoctor, T.S., M.H. Carr, and P.D. Zwick, 2000. *Identifying a linked reserve system using a regional landscape approach: the Florida ecological network*. Conservation Biology 14:4:984-1000.

Hoctor. T. S. 2003. *Regional landscape analysis and reserve design to conserve Florida's biodiversity*. Ph.D. dissertation. University of Florida, Gainesville.

Florida Greenways Commission. 1994. *Report to the Governor: creating a statewide greenways system: for people . . . for wildlife . . . for Florida*. Florida Department of Environmental Protection, Tallahassee.

Carr, Margaret H., Paul D. Zwick, Thomas S. Hoctor, and Mark A. Benedict. *Final Report, Phase II, Florida Statewide Greenways Planning Project*. Department of Landscape Architecture, University of Florida, February, 1999.

Hoctor, T.S., J. Teisinger, M.H. Carr, P.D. Zwick. 2001. *Ecological Greenways Network Prioritization for the State of Florida Final Report*. Office of Greenways and Trails, Florida Department of Environmental Protection. Tallahassee.

Hoctor, T. S., J. Teisinger, M. H. Carr, P. D. Zwick. 2002. *Identification of Critical Linkages within the Florida Ecological Greenways Network Final Report*. Office of Greenways and Trails, Florida Department of Environmental Protection. Tallahassee.

The Florida Ecological Greenways Network was one of the two primary components of the Florida Greenways System. In 1995, Florida began a statewide greenways initiative that included both recreational and ecological components. The Florida Ecological Greenways Network is intended to protect the large, connected areas of ecological significance across the state. The rationale is that a functional reserve network integral to effectively conserving Florida's biological diversity and other natural resources can be identified by using a landscape approach guided by regional conservation planning principles combined with information on areas needed to protect viable populations of target species and natural communities. This was accomplished by incorporating assays of ecological significance, such as locations of rare and listed species, intact ecological communities, habitat areas needed to maintain viable populations of sensitive species, and land use data into a reserve design process integrating these components.

## c. Florida Forever Needs Assessment

Florida Natural Areas Inventory. 2003. *Florida Forever Conservation Needs Assessment Technical Report*. Florida Natural Areas Inventory, Tallahassee.

Oetting, J., and A. Knight. 2004. *Florida Forever Tool for Efficient Resource Acquisition and Conservation*. Florida Natural Areas Inventory. Tallahassee.

The Florida Natural Areas Inventory (FNAI) conducted the assessment to identify priority areas for meeting the goals for the Florida Forever land acquisition program. Critieria included areas important for protecting landscape, natural communities, species, water resources, forest resources, resource-based recreational resources, and archaeological resources. Available GIS data was used to identify the most important areas for protecting these resources. In a second phase, FNAI also conducted a representation/irreplaceability analysis using Marxan/Spexan software to identify the areas most important for meeting the cumulative goals of the Florida Forever program.

**6) Maryland Department of Natural Resources- Maryland Green Infrastructure Assessment and GreenPrint Program**

Maryland Department of Natural Resources. 2003. *Maryland's GreenPrint Program: preserving our green infrastructure and safeguarding Maryland's most valuable ecological lands.* [Online] Retrieved May 7, 2004 at http://www.dnr.state.md.us/greenways/greenprint/.

Weber, T. and J. Wolf. 2000. Maryland's green infrastructure- using landscape assessment tools to identify a regional conservation strategy. *Environmental Monitoring and Assessment* 63: 265- 277.

The Maryland GreenPrint Program is a program led by the Maryland Department of Natural Resources that is intended to identify the most important unprotected natural lands in the state using computer mapping techniques, connect these lands through a system of corridors, and protect lands through acquisitions and easements. The Maryland Green Infrastructure Assessment (GIA) is a component of the GreenPrint Program and was completed in 2000. Its purpose was to provide a scientifically based, landscape approach to identifying and linking regionally ecologically valuable areas within the state. Landscape ecology principles and GIS were used to develop a network of Hubs (large core areas of ecological importance) and landscape linkages (natural routes that connect the Hubs), which were prioritized based on ecological value and risk of loss due to development. Prioritization was done on two scales: by entire Hub or corridor and by individual grid cell (0.137 ha). Only datasets that were available statewide were used in the assessment and included the following: Land Cover (available from Multiresolution Land Characteristics (MRLC) Consortium); National Wetlands Inventory (NWI) Wetlands; Streams, Estuaries, and Atlantic Ocean; Elevation (30 and 90 m Digital Elevation Model); FEMA 100 Year Flood Plains; Wetlands of Special State Concern; National Heritage Areas; Sensitive Species Review Areas; Maryland Biological Stream Survey (MBSS) Living Resource Data; Submerged Aquatic Vegetation (SAV); Protected Lands; Roads; Watershed Boundaries; Natural Soils Groups; State and County Boundaries; Development Pressure; and Generalized County Zoning. All datasets were projected to Maryland State Plane, NAD 1927, and converted to grids with a 0.137 ha (0.34 acre) cell size. The following criteria were used to prioritize Hubs: proportion of natural cover, area of interior forest, area of unmodified NWI wetlands, area of Wetlands of Special State Concern, area of Sensitive Species Project Review Areas, area of Natural Heritage Areas, slope, number of stream sources and junctions, length of headwater streams within interior forest, number of interstate connections, road density, land cover surrounding Hub, and patch shape. Least cost path analysis was used to determine the best ecological routes between Hubs (corridors). The following criteria were used to prioritize corridors: ecological ranking of Hubs connected by corridor, versatility of connection (terrestrial/aquatic/wetland), corridor length, node area along corridor, number of corridor breaks, primary road crossings, secondary road crossings, rail crossings, proportion of natural cover, and land cover surrounding corridor. Hubs and corridors were also ranked according to the following criteria related to the threat of loss due to development: area not protected by regulatory mechanisms, development pressure,

and county zoning.  Cell-based prioritization was based on the following criteria: land cover type, slope, proximity to Wetlands of Special State Concern, presence of interior forest, Sensitive Species Project Review Areas, proximity to streams, biotic integrity of streams, remoteness from roads, proximity to unmodified wetlands, wetland mitigation value, proximity to Natural Heritage Areas, proximity to submerged aquatic vegetation, proximity to first-order streams, proximity to stream sources and junctions.

**7)  New Jersey Department of Environmental Protection Endangered and Nongame Species Program- New Jersey Landscape Project**

Niles, L.J., M. Valent, P. Winkler and P. Woerner. 2004. *New Jersey's Landscape Project, Version 2.0.*New Jersey Department of Environmental Protection, Division of Fish and Wildlife, Endangered and Nongame Species Program. 58. pp.

The New Jersey Landscape Project is a landscape level approach to imperiled species conservation that has been adopted by the New Jersey Department of Environmental Protection (NJDEP) Endangered and Nongame Species Program (ENSP). As part of the Landscape Project, the ENSP has developed maps that identify critical areas for imperiled and priority species based on land-use classification data and imperiled species locations.  For Version 1.0 of the Landscape Project, a raster-based land use/land cover classification developed by Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) was used.  This dataset was based on Landsat Thematic Mapper imagery and was enhanced with data from US Fish and Wildlife Service wetland maps, New Jersey Department of Environmental Protection (NJDEP) freshwater wetland maps and Natural Resource Conservation Service county soil maps. For the updated Landscape Project, Version 2.0, the ENSP used DEP air photo-based land use/land cover data.  Raster-based data was converted to vector-based data for inclusion in the Landscape Project.  Element occurrence data of imperiled species was used to determine critical areas.  Most of the species data used was from the Natural Heritage Program's Biological Conservation Database.  Models were applied to all species data to generate critical area maps.  Critical areas are determined by intersecting imperiled species models with habitat types (forest, grassland, forested wetland, emergent wetland and beach) and then ranking the areas (1 to 5) based on the rank of species within them (5= federally endangered or threatened, 4= state endangered, 3= state threatened, 2= state priority species, and 1= areas that meet habitat requirements but do not intersect with species).  Critical area maps are in ArcView shapefile format and projected to NJ State Plane feet, datum NAD 83, zone 4701.  Landscape Project data is available from the following websites:

http://www.nj.gov/dep/fgw/ensp/landscape/index.htm
http://www.state.nj.us/dep/gis/imapnj/imapnj.htm

Or by contacting:
New Jersey's Landscape Project
Department of Environmental Protection

Endangered and Nongame Species Program
PO Box 400
Trenton, NJ 08625-0400
Phone:(609) 292-9400
Fax:(609) 984-1414

**8)  Defenders of Wildlife- Oregon Biodiversity Project**

Defenders of Wildlife.  1998.  *Oregon's Living Landscape: Strategies and Opportunities
to Conserve Biodiversity.*  Defenders of Wildlife.  219 pp.

The Oregon Biodiversity Project, undertaken by the Defenders of Wildlife, identified conservation opportunity areas within Oregon using an ecoregional assessment. Conservation opportunity areas were identified as areas that "appear to offer opportunities to address multiple conservation objectives."  The assessment methodology is comprised of three main steps, and the first two steps include the use of GIS.  The first step involves overlaying data layers to identify gaps in the existing conservation network, assess changes in historic vegetation patterns, and display areas that have already been identified as having significant biodiversity values.  Data layers that were overlaid in this step included existing vegetation, historical vegetation, aquatic diversity areas, at-risk plant and animal species, salmon core areas, wilderness study areas, and the existing conservation network.  The existing vegetation data layer was based on a digital map developed for the Oregon Gap Analysis Program (GAP) and was developed through interpretation of 1:250,000 scale satellite photos.  The historic vegetation data layer is a map created using three main sources: a historic vegetation map developed by the federal government's Interior Columbia River Basin Ecosystem Management Project, a forest vegetation type map created by H.J. Andrews et al. of the U.S. Forest Service, and maps created for the Oregon Natural Heritage Program, which were based on General Land Office plat maps for periods between 1850 and 1870.  The aquatic diversity areas data layer was created using several sources of data from the Oregon Critical Watersheds Database that were created by the Oregon Chapter of the American Fisheries Society and included reference watersheds, genetic refuges, centers of species richness, ecological functions, and connecting corridors.  The at-risk plant and animal species data layer was created from Oregon Natural Heritage Program Database data.  Location data of more than 400 species that were considered "at-risk" because of their classifications as "vulnerable," "imperiled," or "critically imperiled" were included.  The salmon core areas data layer is data that was developed by the Oregon Coastal Salmon Restoration Initiative (1996).  The existing conservation network data layer is a map created by the Oregon Biodiversity Project that identifies areas that received a biodiversity management rating of 8, 9, or 10 on a 1 to 10 scale rating areas according to their contributions to long-term conservation of biodiversity under current management.

The second step of the Oregon Biodiversity Project ecoregional assessment was evaluation of landscapes for their potential to address ecoregional and statewide conservation priorities.  The following criteria were included: large blocks of native habitat, vegetation types or habitats that have experienced major declines from historic levels, vegetation types that are not well protected in the current conservation network,

at-risk species, and potential to complement or connect elements of the existing network of conservation lands.

The final step of the methodology was a subjective decision process that was based on several factors: land ownership, current management, existing and potential programs to implement conservation actions, pending public policy decisions, and potential future threats.

## 9) **Natural Heritage and Endangered Species Program, Massachusetts Division of Forestry and Wildlife - Massachusetts BioMap Project**

Natural Heritage and Endangered Species Program, Massachusetts Division of Forestry and Wildlife. 2002. *BioMap.* [Online] Retrieved May 10, 2004 at http://www.state.ma.us/dfwele/dfw/nhesp/nhbiomap.htm

The Natural Heritage and Endangered Species Program of the Massachusetts Division of Forestry and Wildlife developed the BioMap to identify the areas most in need of protection in order to protect the native biodiversity of the State of Massachusetts. The BioMap Project primarily focuses on state-listed rare species and exemplary natural communities; however, identifying the areas that would provide suitable habitat for the maximum number of terrestrial and wetland plant and animal species and natural communities over the long term was also a primary goal. For the project, core habitat and supporting natural landscape was mapped. Core habitat was based on Natural Heritage element occurrence data of rare plant and animal species and assemblages of common species and consisted of areas that were expected to support viable populations. Habitat boundaries were delineated using aerial photography and GIS mapping and were incorporated into the BioMap. Natural community boundaries were delineated by using field data, expert input, color infrared aerial photography, and GIS mapping. Supporting natural landscape was mapped by using a GIS analysis that ranked undeveloped areas not already mapped as core habitat and included buffers of core habitat, large roadless areas, and undeveloped watersheds. BioMap data may be downloaded from http://www.state.ma.us/mgis/laylist.htm.

## 10) **ESRI tools for watershed assessment**

Environmental Systems Research Institute. 2001. *ArcGIS Hydro Data Model (ArcHydro)*. [Online] Retrieved 01/30/2004 at http://support.esri.com/index.cfm?fa=downloads.dataModels.filteredGateway&dmid=15.

Summary:
The ArcGIS Hydro data model is an ESRI geodatabase that describes the geospatial and temporal data of surface water resource features of natural water systems on the landscape. The data model addresses the principle water features of the landscape, water movement from feature to feature, and the time patterns of water flow and water quality associated with these features. The ArcHydro data model consists of hydrologic

features, which describe the physical environment through which water flows, and the time series that describe the flow and water quality properties of the water within those features. Hydrologic features are unique from each other, and can be linked to other hydrologic features by common attributes to trace the movement of water from one feature to the next. The time series data are also linked to hydrologic features by attributes.

The connectivity of water flow through the landscape is described as a water resource network that describes the flow of water through rivers and streams, and the centerlines of waterbodies represented by edges (stream channel segments), which are connected by junctions (confluences between two stream channel segments). In the drainage component the land surface topography, which can be represented by a digital elevation model or from a digital image of the area, defines the direction of surface water flow. Topographic features described by drainage includes drainage divides, topographic ridge lines separating one drainage area from another, drainage networks (stream channel networks on the landscape), catchments, basins, and watersheds (specific types of drainage areas), and drainage points (outlets on drainage networks defining the outlets of drainage areas). The channel component provides a three-dimensional representation of the river and stream channel shape, which is used for studies of flood inundation, stream ecology and morphology. Channel information for stream thalweg line, banklines, and cross sections can be collected in the field using surveying techniques, or by extracting the data from digital terrain models (DTMs) in the form of a triangulated irregular network (TIN), or digital elevation model (DEM). The hydrography component contains the map representations of surface water features comprising either points, lines, or polygons derived from the "blue lines" or hydrography layer of topographic maps. Hydrography can represent polygonal waterbody features, such as lakes, bays and estuaries; and point features derived from tabular data inventories, such as dams, bridges, structures, monitoring points (gages and sampling points), points of water withdrawal and water discharge, and user points for any other purpose. The water properties such as discharge, water surface elevation, or water quality, at any geographic location within a watershed are important in hydrologic analyses. The Time Series component of ArcHydro represents these water properties whose values vary in time, which are connected to a specific spatial features defined within ArcHydro for a watershed. The Time Series component is essentially a table that contains any types of time series hydrologic/climatic data, e.g. precipitation, streamflow, or reservoir surface elevation.

The ArcHydro database model represents a first attempt at standardizing the input storage, and representation of hydrologic features within a hydrologic modeling framework. Based on ESRI's geodatabase design, ArcHydro effectively, and efficiently stores geographic and tabular information about the hydrologic features and attributes of a watershed. ArcHydro has the potential to model, in a database context, the complete hydrologic representation of a watershed from its headwaters to the outlet, with the ability to store streamflow, precipitation, and other aspatial, description data. Although not currently used for regional scale watershed and ecosystem assessments, the design of ArcHydro lends itself to store large volumes of GIS and aspatial hydrologic data for regional extent assessments. Already with a robust description of a watershed and its features, ArcHydro may continue to evolve to store more data, and represent more

complex relationships within a watershed, and other natural systems, such as geomorphology, groundwater systems, and aquatic ecosystems.

Spatial Extent
From individual 14-digit USGS HUC watersheds, to national extent subdivided into 4- or 8-digit HUC watersheds. Any user-defined watershed based on the desired position of the outlet.

SAB Reporting Categories:
Hydrology and Geomorphology (Dynamic Structural Characteristics, Surface and Groundwater Flows).

GIS Tools:
ESRI's ArcHydro ArcGIS Geodatabase model.


## 11) Advances in Watershed Assessment Techniques

### a.  Bhaduri et al.- Assessing Watershed-Scale, Long-Term Hydrologic Impacts of Land-Use Change

Bhaduri, B., J. Harbor, B. Engel, and M. Grove.  2000. Assessing watershed-scale, long-term hydrologic impacts of land-use change using a GIS-NPS model. *Environmental Management* 26 (6): 643-658.

Summary:
A Long-Term Hydrologic Impact Assessment (L-THIA) model has been developed using the curve number (CN) method. Long-term climatic records are used in combination with soils and land-use information to calculate average annual runoff and NPS pollution at a watershed scale. The model is linked to a geographic information system (GIS) for convenient generation and management of model input and output data, and advanced visualization of model results. Historical land-use scenarios for 1973, 1984, and 1991 are analyzed to track land-use change in the watershed and to assess impacts on annual average runoff and non-point source (NPS) pollution from the watershed and its five sub-basins. Results show urban areas increased runoff volume and metal concentrations, whereas agricultural lands contribute most to nutrient pollution. This model can be operationalized for any watershed provided the necessary input data are available to parameterize the model. The L-THIA/NPS GIS model is a powerful tool for identifying environmentally sensitive areas in terms of NPS pollution potential and for evaluating alternative land use scenarios for NPS pollution management.

Spatial Extent:
Little Eagle Creek watershed (70.5km2), Indianapolis, Indiana

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics and its subcategories of Nutrient Concentrations and Trace Inorganic and

Organic Chemicals. It also addresses stressors such as land use change, nutrient enrichment, water quality impacts, development potential and agricultural intensification.

GIS tools:
The Long-Term Hydrologic Impact Assessment Model (L-THIA) runs through ArcView GIS. A specialized interface was created using ArcView GIS Avenue language for the data input and parameter specification, and model operation.
GIS datasets including land use classified from Landsat MSS imagery, SSURGO soils (1:16000), and watershed boundary delineated from DEM

## b. Burian et al.- Evaluation of Land Use/Land Cover Datasets for Urban Watershed Modeling

Burian, S.J., M.J. Brown, and T.N. McPherson. 2002. Evaluation of land use/land cover datasets for urban watershed modeling. *Water Science and Technology* 45 (9): 269-276.

Summary:
Land use/land cover (LULC) datasets are compared with each other using a hydrologic model to simulate in three urban watersheds the annual runoff volume and total suspended solids. LULC control important hydrologic processes like runoff and infiltration and therefore are important data in the context of environmental modeling. Certain LULC types, like urban, can contribute to non-point source pollution. It is necessary to identify those LULC types that contribute to the degradation/conservation of a watershed.

Spatial Extent:
Three urban watersheds near Los Angeles totaling about 300km2

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics, and Hydrology and Geomorphology, and their respective subcategories of Nutrient Concentrations and Surface and Groundwater Flows, and Sediment and Material Transport. It also addresses stressors such as land use change, alterations of natural process regimes, development potential and agricultural intensification.

GIS tools:
USGS LULC data National Land Cover Dataset (NLCD) 30m spatial resolution
Southern California Association of Governments LULC data 0.25ha spatial resolution
EPA Storm Water Management Model (SWMM)

## c. Bhuyan et al.- An Integrated Approach for Water Quality Assessment of a Kansas Watershed

Bhuyan, S.J., J.K. Koelliker, L.J. Marzen, and J.A. Harrington. 2003. An integrated approach for water quality assessment of a Kansas watershed. *Environmental Modelling & Software* 18 (5): 473-484.

Summary:
The Agricultural Non-Point Source Pollution (AGNPS) Model in conjunction with a custom ArcINFO interface was applied for the assessment of nutrient loadings to the sub-watersheds of the Cheney Reservoir watershed. The model was created using readily available remotely sensed satellite data, and GIS data for soils other watershed features accessible from national and statewide governmental agencies. The interface provided "data generation, input file creation, program execution, and AGNPS out-put file extraction." Compared to measured observation, simulated nutrient loadings were adequately represented, but accurate results are dependent upon the spatial distribution of rainfall, land cover types and extents, and the degree of spatial averaging within each sub-watershed.

Spatial Extent:
Cheney Reservoir watershed (~2400km2) located in south central Kansas

Analysis Categories:
This article addresses the SAB reporting category of Chemical and Physical Characteristics and Hydrology and Geomorphology, and their discrete subcategories of Nutrient Concentrations and Surface and Groundwater Flows. Additionally, it addresses stressors including land use change, development potential and agricultural intensification.

GIS tools:
ArcInfo GIS
United States Department of Agriculture (USDA) Agricultural Non-Point Source Pollution (AGNPS) Model
ArcINFO-AGNPS interface (Liao and Tim, 1997)
Land cover data from classified Landsat TM imagery (30m pixel resolution)
NRCS 1:24K STASGO (State Soil Geographic) soils
From Kansas Geological Survey: streams layer; points for the location of the feedlots and wastewater treatment plants in the Cheney Reservoir watershed; impoundments within the watershed; the locations of conservation measures being taken; 7.5-min digital elevation model (DEM)

**d.  Payraudeau et al.- Annual Nutrients Export Modelling By Analysis of Landuse and Topographic Information**

Payraudeau, S., M.G. Tournoud, F. Cernesson, and B. Picot.  2001. Annual nutrients export modelling by analysis of landuse and topographic information: case of a small Mediterranean catchment. *Water Science and Technology* 44 (2-3): 321-327.

Summary:
ARCINFO GIS is used to assess the annual nutrient loadings (phosphorus and nitrogen) to a small watershed in France. The analysis employs readily available GIS data from satellite sources and governmental agencies, whereby land cover type and extent exerts

the dominant control on nutrient production. The analysis results are comparable to field measured experimental data and identify the location and quantity of nutrient production.
Spatial Extent:
Small watershed

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics and Hydrology and Geomorphology, and their individual subcategories of Nutrient Concentrations, and Surface and Groundwater Flows. Additionally, it addresses stressors such as land use change, nutrient enrichment, development potential, agricultural intensification, and water quality impacts.

GIS tools:
ARCINFO GIS (GRID, NETWORK, hydrologic/geomorphic functions for stream network delineation)
50 m DEM
1:50,000 scale hydrographic network
1:50,000 scale pollution point sources
Land uses coverage classified from a 1996 SPOT satellite image (20 m resolution)

### e. McQuaid and Norfleet- Assessment of Two Carolina Watersheds Using Land and Stream Habitat Quality Indices

McQuaid, B.F. and L. Norfleet, , 1999. Assessment of two Carolina watersheds using land and stream habitat quality indices. *Journal of Soil and Water Conservation* 54 (4): 657-665.

Summary:
The main objective of this study was to "field test five indices of land, biotic, stream physical habitat, and riparian condition for NRCS use; and … compare these indices in two watersheds." The indices include Stream Habitat Assessment (SHA); Visual Stream Assessment (VSA); Index of Biotic Integrity (IBI); Riparian Vegetation Index (RVI); and Land Quality Index (LQI). A third objective was to develop a statistical framework to study relationships among these health indices on a watershed scale. The best correlation was noted between the SHA and VSA scores, probably because both were developed to describe stream physical habitat. Overall, the SHA, VSA, and RVI rated the condition of both watersheds as good, whereas, the IBI rated these as fair. All indices lacked a strong correlation to IBI, perhaps indicating these indices measure different features in the watersheds. The LQI was developed to characterize watershed land use and management, and compared to the IBI scores.

Spatial Extent:
The Rocky River watershed North Carolina [320,000 ha (800,000 ac)] and the Saluda River watershed South Carolina [400,000 ha (1,000,000 ac)]

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics, Landscape Condition, Biotic Condition, and Hydrology and Geomorphology, and their individual subcategories of Nutrient Concentrations, Extent of Ecological System/Habitat Types, Ecosystems and Communities, Species Populations, Organism Condition, and Surface and Groundwater Flows. Additionally, it addresses stressors such as water quality impacts and nutrient enrichment.

GIS tools:
ArcView GIS
Hydrology and topographic data provided by the NRCS and US Geological Survey
The resulting indices were assigned to each sub-basin in the GIS.

## f. Griffith et al.- Ecoregions, Watersheds, Basins, and HUCS: How State and Federal Agencies Frame Water Quality

Griffith, G.E., J.M. Omernik, and A.J. Woods. 1999. Ecoregions, watersheds, basins, and HUCs: How state and federal agencies frame water quality. *Journal of Soil and Water Conservation* 54 (4): 666-677.

Summary:
A regional ecoregion spatial framework is proposed for the assessment and management of the watersheds and water quality. Though watersheds are natural divisions of the landscape as controlled by hydrology their boundaries do not coincide with "regional characteristics, such as …soils, vegetation, geology, climate, and land use … influence the physical, chemical, or biological nature" of watersheds. This regional approach proposes a more holistic and integrative to watershed assessment and management potentially incorporating all aspects of the ecosystem under study. A mid-point between watersheds and ecoregions are hydrologic unit codes (HUC), which can encompass multiple watersheds and serve as a spatial unit of study. Currently, the USDA and US EPA recommend HUCs as "common units for determining condition, reporting results, and targeting resources" in watersheds. Watersheds and HUCs are inappropriate for state and regional studies due to difficulties in the extrapolation of spatial patterns for controls on water quality or environmental characteristics observed at these smaller investigative units to larger spatial extents. "Management strategies regarding protective water quality standards or restoration goals can be more effective if regional differences in ecological capabilities and potentials are considered." Ohio has used ecoregions, reference sites, and biological criteria to inform decision-makers, managers, and the public about the quality and condition of its surface waters. Florida due to its ecologically/hydrologically complex nature uses multiple spatial extents (e.g. basins, eco/bioregions, lakes, HUCs) for its ecosystem management approaches.

"It is becoming evident that a variety of spatial frameworks at different scales might be needed to help integrate landscape data, reference site data, historical and current in-stream data, and expert knowledge to better define attainable conditions for water quality and aquatic life." In summary "…water resources can be assessed and managed more

effectively by using a framework that reflects the regional differences in their quality, quantity, hydrology, and their sensitivity or resilience to ecological and cultural disturbances."

Spatial Extent:
Three case studies are given: Regional (mid-Atlantic states) and state (Ohio and Florida)

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics (subcategory of Nutrient Concentrations, Trace Inorganic and Organic Chemicals, and Other Chemical Parameters), Hydrology and Geomorphology (subcategory of Surface and Groundwater Flows) and Landscape Condition (subcategory of Extent of Ecological System/Habitat Types). Stressors, including nutrient enrichment, land use change, and alteration of natural process regimes are also addressed.

GIS tools:
None.
The USGS is mentioned as providing hydrologic unit code (HUC) data for the entire United States and Caribbean in addition to "watershed networks, such as the U.S. Geological Survey (USGS) Hydrologic Benchmark Network and the USGS National Stream Quality Accounting Network."
STATSGO general soils mentioned with respect to Florida's ecosystem management initiatives.

### g.  Johnston et al.- Multimedia Integrated Modeling for Environmental Protection: Introduction to a Collaborative Framework

Johnston, J.M., J.H. Novak, and S.R. Kraemer. 2000. Multimedia integrated modeling for environmental protection: Introduction to a collaborative framework. *Environmental Monitoring and Assessment* 63 (1): 253-263.

Summary:
The EPA's Office of Research and Development (ORD) is planning for release in 2008 a Multimedia Integrated Modeling System (MIMS) to "represent the transport and fate of nutrients and chemical stressors over multiple temporal and spatial scales." This computer-based environmental assessment system will evaluate "the impact of air and water quality and watershed management practices on stream and estuarine conditions." In effect, the interactions of air, land and water will be simulated using physically based modeling components integrated into one software package served across the Internet.

A brief history of ecosystem assessment model development by the EPA is provided. Early models corresponded to Federal law mandates and analyzed the protection of individual components of an ecosystem, not the entire ecosystem. No common model was used to conceptualize the complete ecosystem. Subsequent models investigated the fate and transport of toxic compounds. Early air pollution models simulated transport and decay of chemicals without interactive effects whereas second generation models were

spatially explicit including transport and transformation reactions but limited to a specific scale and pollutant type. The present air model (Model3) include all components of past models built on object-oriented approach, encompassing multiple pollutants and air quality indicators, and viable from urban to regional scales. Modules for hydrology and aquatic and terrestrial ecosystems are not included in this current air model. Inclusion of these components into Model3 represented on a physical basis to overcome calibration issues will serve as a foundation for MIMS whereby atmospheric, aquatic, and terrestrial components will be linked for data transfer. MIMS will be a holistic approach for "performing ecological risk assessment and management of aquatic systems at the watershed scale" by way of physically-based representation of solute, pollutant, and particle transport simulating the hydrologic and biogeochemical cycles associated with water budgets and mass conservation of nutrient and pollutants.

Spatial Extent: watershed/ecological system extents

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics (subcategory of Nutrient Concentrations), Hydrology and Geomorphology (subcategory of surface and Groundwater Flows), Landscape Condition (subcategory of Extent of Ecological System/Habitat Types), and Biotic Condition (subcategories of Ecosystems and Communities, Species Populations, and Organism Condition). It also addresses stressors such as nutrient enrichment, land use change, and alteration of natural process regimes.

GIS tools:
MIMS software consisting of a coupled atmospheric-hydrospheric model, ecological model, and a land-use change model (not specifically named, but proposed at this point); common, shared input/output data libraries consisting of [presumed spatially explicit] datasets of hydrodynamic and water quality, current and historic land use, fish community, and aquatic ecology information

**h. Garen et al.- A User Agency's View of Hydrologic, Soil Erosion and Water Quality Modelling**

Garen, D., D. Woodward, and F. Geter. 1999. A user agency's view of hydrologic, soil erosion and water quality modelling. *Catena* 37 (3-4): 277-289.

Summary:
Current agricultural/erosion/water quality models employed by the National Resources Conservation Service (NRCS) are evaluated based on their strengths and weaknesses for effective land management and conservation measures. Five models (AGNPS, EPIC, GLEAMS, NLEAP, and SWRRB) exist for simulation of erosion/water quality produced by agricultural lands at the field level and catchment extent. Additionally, the RUSLE and WEPP models have gained some attention, with concerted effort to implement RUSLE into field offices, and WEPP needed NRCS evaluation for potential use. Improvements in accurate precipitation input, representation of water fluxes and runoff

generation; and accurate erosion and hydrologic process description are targeted for current and future model development. Model application issues are addressed, which consist of model choice and potential redundancy between models; model regionalization and calibration; interpretation of results (absolute vs. relative output; implying greater accuracy of results); and user issues of ease model use, data availability, modeler expertise and training. The USDA has found itself as a software vendor that has to develop, maintain, enhance, and support the models. Current progress includes new model development, improvement of runoff generation and erosion mechanisms, practical model applications using training and result interpretation, more efficient model development and maintenance, all o which lead to better agricultural land management, and decision making.

Spatial Extent: Field to watershed to, potentially, regional extent.

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics (subcategory of Nutrient Enrichment) and Hydrology and Geomorphology (subcategories of Surface and Groundwater Flows and Sediment and Material Transport). Additionally, stressors including alteration of natural process regimes are addressed.

GIS tools:
None explicitly mentioned. However, multiple water quality and erosion models are named (see Summary above) and input data of soils, land use, and other physical characteristics of a study area under investigation are mentioned.

**i.  Reynolds et al.- Knowledge-Based Assessment of Watershed Condition**

Reynolds, K.M., M. Jensen, J. Andreasen, and I. Goodman. 2000. Knowledge-based
        assessment of watershed condition. *Computers and Electronics in Agriculture* 27
        (1-3): 315-333.

Summary:
The Ecosystem Management Decision Support (EMDS) system was developed cooperatively between the USDA Forest Service and the US EPA for the environmental "assessment and monitoring of ecological states and processes in sixth-code watersheds" (10,000 to 20,000 ha). EMDS is constructed on a NetWeaver knowledge base founded on the concept of "fuzzy logic" that incorporates GIS data and knowledge base system technologies for ecological landscape analysis at any geographic scale. The objectives of EMDS are to improve the quality, completeness, and efficiency for evaluating watershed processes, patterns, general effects of human influence, and specific effects on salmon habitat. The "knowledge base" used in the EMDS stems from establishment of non point source pollution (NPS) total maximum daily loads (TMDLs) by EPA's Clean Water Act, which include streamflow, stream temperature, nutrients, stream sediment, and in-channel stream habitat. Additionally, watershed processes, watershed patterns, general effects of human influence, and specific effects of human influences on aquatic species are also included in the knowledge base.

The US EPA has established a five-step approach to setting NPS TMDLs that identifies waters requiring TMDLs; prioritizes watershed and stream ranking and targeting; developing TMDLs, implements control actions; and assesses control actions. The analysis results suggest that a knowledge-based approach to landscape analysis for TMDL assessment generally is feasible because the conduct of a comprehensive analysis differs very little in principle from the small example given. The key advantages of a landscape analysis based on fuzzy logic networks as implemented in NetWeaver and used in EMDS include the ability to reason with incomplete information, and the ability to evaluate the influence of missing information.

Spatial Extent:
Watersheds of any geographical extent; the example used here is a small portion of the Columbia River Basin

Analysis Categories:
This article addresses the SAB reporting categories of Chemical and Physical Characteristics (subcategory of Nutrient Enrichment), Hydrology and Geomorphology (subcategory of Surface and Groundwater Flows), Landscape Condition (subcategory of Extent of Ecological System/Habitat Types), and Biotic Condition (subcategories of Ecosystems and Communities, Species Populations, and Organism Condition). It also addresses stressors such as nutrient enrichment, land use change, and alteration of natural process regimes.

GIS tools:
None specifically stated; this paper provides a conceptual modeling approach for landscape analysis at the watershed extent.

## j. Soil and Water Assessment (SWAT) Model

Missouri Department of Natural Resources. 2003. *Total Maximum Daily Loads (TMDLs) for Shoal Creek, Newton and Barry Counties, Missouri.* Missouri Department of Natural Resources Water Pollution Control Program. Completed: October 2003, Approved: November 2003. [Online] Retrieved 12/29/2004 at http://www.epa.gov/region7/water/pdf/shoal_creek_final_TMDL.pdf.

Summary:
Shoal Creek watershed (440 mi2) in southwestern Missouri has experienced a significant increase from 1992 to 1999 in fecal coliform bacteria counts that are much greater than the permitted threshold for the needed use of recreation. Additionally the creek supplies water for irrigation, consumptive water source, fisheries, and wildlife habitat. Located in a rural setting with a predominantly pasture land use, animal agriculture and potentially failing septic systems were identified as possible sources of the increase. Given the potential non point source of fecal coliform, the Soil and Water Assessment (SWAT) model is used to develop total maximum daily loads (TMDLs) for fecal coliform input into the Shoal Creek watershed.

The SWAT computer model mathematically simulates the physical processes of the land-based hydrologic cycle that can impact water quality. SWAT also simulates the physical processes controlling water movement, sediment transport, crop growth, nutrient cycling and transport and other processes on a daily time step. The model requires inputs of GIS data layers for elevation, soils, slopes, and land use; qualitative information about pasture management, litter management and grazing practices; and climatic data for daily rainfall and temperature to calculate flow values, sediment yields, pollutant loads and concentrations, as well as crop yields. The purpose of using SWAT is to integrate stream flow and water quality data to establish water quality baseline characteristics to determine impacts from fecal coliform loadings. The Shoal Creek watershed was divided into sub-basins and further sub-divided into nearly homogeneous units called hydrologic response units (HRU) that have distinct land uses, soils and management practices. Validation of the model requires calculated values for surface runoff, hay yields and the movement of agricultural chemicals that were compared to measured values derived from actual data. Water quality is analyzed at the outlet of each sub-basin of the watershed. After establishing a baseline, SWAT evaluates the potential change in environmental impact if land management practices change within the watershed and along riparian corridors.

The following scenarios assessed by simulations of the SWAT model show the most promise for reducing the fecal coliform concentrations in Shoal Creek:

A 100 percent reduction of the sanitary sewage that reaches the stream

A 50 – 100 percent reduction of the cattle standing in the streams

A 66 percent reduction in the fecal coliform loadings due to surface runoff events Implementation of this TMDL to achieve these reductions includes reduction of reduction of the cattle standing in the streams through the use of fencing and riparian vegetation buffers; vegetated filter strips at the downstream edge of the pastures to reduce fecal coliform loadings in surface runoff; and the enforcement of a local law restricting sanitary sewage from leaving a landowner's property.

Identification of ecologically sensitive stream reaches can be identified in a timely fashion with commonly available data. The software needs (GIS and SWAT) are reasonable and can be employed readily and easily in any EPA regional office. The SWAT model is well documented in the scientific literature and has precedent for yielding good modeling results for determining stream flow, sediment yields, and pollutant/nutrient loadings. SWAT has good user documentation, and could be applied in any EPA region at regional spatial extents. The data used by the model are readily available at the national level, which is viable for subsetting to the regional extent. The model runs on raster based GIS data but the results are presented visually and tabular at the hydrologic response unit level yielded quasi-distributed output. The input data, model, and results are spatially explicit, dependent on the data layer with the largest grain resolution.

Extent:
440 square miles

Analysis Categories:
SAB reporting categories addressed by SWAT include the following:

Chemical and Physical Characteristics (Water) –All subcategories; Hydrology and Geomorphology - Surface and Groundwater Flows, and Sediment and Material Transport

GIS Tools:
Soil Water Assessment Tool distributed by the USDA AGRICULTURAL RESEARCH SERVICE
GIS data layers for elevation, slopes, soils, and land use, all of which can be found readily from the Internet

### k. Singh and Woolhiser- Mathematical Modeling of Watershed Hydrology

Singh, V. P., and D. A.Woolhiser. 2002. Mathematical Modeling of Watershed Hydrology. *Journal of Hydrologic Engineering* 7(4):4270–29.

Summary:
A watershed hydrology model contains mathematical equations that describe components of the hydrologic cycle. Singh and Woolhiser (2002) provide a discussion of the historical development and classification of mathematical hydrologic watershed models with emphasis on the current, most commonly used models, data sources, data management, and methods of data acquisition, and future directions and issues needing attention, including spatial and temporal scaling problems. Approximately ninety models are listed with author references with the more common models used in private and regulatory sectors that include the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) developed by the US Army Corps of Engineers, Hydrologic Engineering Center for hydrologic engineering design, Hydrologic Simulation Program – Fortran (HSPF) developed by the EPA for assessment of water quality, and the Modular Modeling System (MMS) developed by the US Geological Survey for water resources planning and management. Watershed models are a viable tool for water resources planning, development, and management with promise for use in ecological assessments, particularly those using water quality and sediment transport models for identifying critical areas within a watershed with important hydrologic and ecological functions for maintaining the balance and health of the watershed ecosystem. Through watershed simulation using mathematical models values of instream water quantity and quality can be estimated, which allows recreational, ecological, and biological concerns to coexist with traditional consumptive uses. A review is given emphasizing the pioneering researchers who developed mathematical equations for modeling each component of the land based hydrologic cycle. The development of watershed based mathematical models concurrent with computer technology allowed for the integration of the individual hydrologic components to provide a more holistic approach/view to watershed hydrology simulated in a somewhat accurate but simplified manner. Although mathematical modeling of watershed processes has advanced considerably in the past three decades, there are many issues that need attention, including model validation, error propagation, and analyses of risk, uncertainty, and reliability, for more robust and accurate portrayal of watershed hydrology. This paper provides a very good review of the current state in mathematical watershed modeling, including the types of models currently used, and the types of data available for input.

Additionally, a lengthy bibliography providing sources for further investigation into the development, mathematical formulation, and application of watershed models. This discussion could serve as a detailed primer of model types and modeling considerations to those unfamiliar with mathematical watershed modeling.

Spatial Extent:
Any user-defined watershed based on the desired position of the outlet up to the size limit of the model.

SAB Reporting Categories:
Chemical and Physical Characteristics (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Surface and Groundwater Flows)

GIS Tools:
Approximately 90 models are listed with the most common watershed scale hydrologic and water quality models of the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS), Hydrologic Simulation Program – Fortran (HSPF), Modular Modeling System (MMS).

## l.  Borah and Bera- Watershed-Scale Hydrologic and Nonpoint-Source Pollution Models: Review of Mathematical Bases

Borah, D. K., and M. Bera. 2003. Watershed-Scale Hydrologic and Nonpoint-Source Pollution Models: Review of Mathematical Bases. *Transactions of the ASAE* 46(6): 1553- 1566.

Summary:
This paper reviews eleven common watershed-scale hydrologic and nonpoint-source pollution models and provides a summary of their mathematical basis and formulation, and gives recommendations for appropriate uses and watershed scales for application. The models reviewed include Agricultural NonPoint Source pollution model (AGNPS), Annualized Agricultural NonPoint Source model (AnnAGNPS), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), ANSWERS-Continuous, CASCade of planes in 2-Dimensions (CASC2D), Dynamic Watershed Simulation Model (DWSM), Hydrological Simulation Program - Fortran (HSPF), KINematic runoff and EROSion model (KINEROS), the European Hydrological System model (MIKE SHE), Precipitation-Runoff Modeling System or (PRMS), and Soil and Water Assessment Tool (SWAT). Mathematical watershed-scale hydrologic and non-point source models are useful analysis tools to understanding and evaluating watershed processes that lead to impairments through land use change and water quality issues, and to evaluate potential solutions for remediation. Watershed models are also useful for identifying important hydrological and ecologically sensitive areas within a watershed and to develop best management practices (BMPs) total maximum daily load (TMDL) standards. Watershed models

differ in the mathematical representation of water, chemical, and sediment flow, which are based on the St Venant equation that account for mass and energy balance and conservation within a hydrologic system. Understanding of these equations and their many forms is important to appropriately applying watershed models to a specific water quantity or quality problem. This review is useful for providing a user with sufficient information for selecting the most suitable model based on mathematical form for an application dependent on the problem, watershed size, desired spatial and temporal scales, expected accuracy, user's skills, computer resources while identifying the strengths and weaknesses of each model. The models are further classified into Single event and continuous models based on the simulation length of a hydrologic/meteorological event under investigation. Single event models are useful for addressing development of BMPs particularly structural BMPs, and continuous models are useful for analyzing long-term effects of hydrological changes and watershed management practices, especially agricultural practices. The SWAT and HSPF models have been used extensively in recent years due to their adoption in the USEPA's BASINS modeling software package for developing TMDL standards and guidelines. Each of the evaluated models have strengths and weaknesses that make more appropriate for applications given their mathematical form, watershed size, and the problem under investigation. This paper provides an in-depth review of the more common, contemporary hydrologic and non-point source pollution water quality models useful for a myriad needs for assessing water quantity and quality for development of BMPs and TMDLs necessary for identifying and protecting critical hydrologic and ecologically sensitive areas important for maintaining the health and function of a watershed.

Spatial Extent:
Any user-defined watershed based on the desired position of the outlet up to the size limit of the model.

SAB Reporting Categories:
Chemical and Physical Characteristics (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Surface and Groundwater Flows)

GIS Tools:
Watershed-scale hydrologic and nonpoint-source pollution models: Agricultural NonPoint Source pollution model (AGNPS), Annualized Agricultural NonPoint Source model (AnnAGNPS), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), ANSWERS-Continuous, CASCade of planes in 2-Dimensions (CASC2D), Dynamic Watershed Simulation Model (DWSM), Hydrological Simulation Program - Fortran (HSPF), KINematic runoff and EROSion model (KINEROS), the European Hydrological System model (MIKE SHE), Precipitation-Runoff Modeling System or (PRMS), and Soil and Water Assessment Tool (SWAT).

**m.  Garbrecht et al.- GIS and Distributed Watershed Models. I: Data Coverages and Sources**

Garbrecht, J, F.L. Ogden, P.A. DeBarry, D.R. Maidment. 2001. GIS and Distributed
    Watershed Models. I: Data Coverages and Sources. *Journal of Hydrologic
    Engineering* 6 (6): 506-514.

Summary:
        This paper provides an overview of selected topics important to the integration
and implementation of GIS data and hydrologic modeling; identifies GIS capabilities,
data availability, sources, specifications, and processing needs, as well as data quality,
limitations and uncertainties; and helps the potential user with understanding of the
practices and issues of using spatial GIS data for hydrologic modeling applications. The
purpose of this paper is to provide an overview of the data-GIS-hydrologic modeling
issues and a source of background information for selection and application of GIS
technologies and data in watershed modeling. Vector and raster data structures are
covered with an overview of the advantages and disadvantages of each, and example are
given of common representation of spatial watershed features using each data structure.
Map projections, the representation of the three-dimensional earth in two-dimensional
space, need to be standardized when compiling spatial data from multiple sources. Users
generally have the least amount of knowledge about map projection, datums, and map
projection parameters making it more complicated in preparing GIS data for hydrologic
modeling. Examples are given of common types of projections and the types of datums
used most often in the United States. Topography or elevation is represented using digital
elevation models (DEMs) in raster matrix, triangulated irregular network, or contour-
based models with advantages and disadvantages given for each data structure. DEMs
provide the foundation for spatially explicit hydrologic modeling, and are used to
delineate watershed boundaries and stream networks for many hydrologic models. The
vertical accuracy of the elevation data along with the resolution, the vertical elevation
increment and the horizontal grid spacing are Important aspects when selecting a DEM
product or for construction from other elevation data. Sources for digital stream network
are given with information about hydrologic feature type, scale, and data format. Other
types of GIS data necessary for GIS-based hydrologic modeling applications include soil
data, state level STATSGO and county level SSURGO distributed by US Department of
Agriculture National Resources Conservation Service, and digital orthophoto quadrangles
distributed by the US Geological Survey for base map and geographic location of study
areas. The continuous spatial coverage of a geographic area using remote sensing of
hydrologic/meteorological variables has become increasingly common to derive input
parameters for GIS-based, spatially distributed hydrologic modeling. Precipitation, land
use/land cover, vegetation indices derived from satellite band ratioing, drainage basin and
stream networks, land surface temperatures, soil moisture, and snow cover are examples
of remotely sensed derived hydrologic data for use in modeling. Common sources for
precipitation data include measurements by rain gauge and radar estimates, which are
available from the NOAA National Climatic Data Center online and through the National
weather Service. Issues about the accuracy of radar-derived rainfall are given. GIS data
are available from many state, federal, and commercial organization in different formats,

projections, and resolutions, all of which need to be standardized for use in modeling applications. These data allow for spatially explicit representation of major watershed features permitting spatially distributed hydrologic modeling. Although previously collected GIS data are primarily static, remote sensing of hydrologic variables provides opportunities for more dynamic and updated watershed representation and modeling.

Spatial Extent:
Any user-defined watershed based on the desired position of the outlet up to the size limit of the model.

SAB Reporting Categories:
Chemical and Physical Characteristics (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Surface and Groundwater Flows)

GIS Tools:
None mentioned specifically; general reference is made to the following: vector and raster data models, map projections and datums, DEMs, digital stream networks, USDA-NRCS soils (STATESGO and SSURGO), and hydrologic input products for modeling derived from remote sensing.


## n. Ogden et al.- GIS and Distributed Watershed Models. II: Modules, Interfaces, and Models

Ogden F.L., J. Garbrecht, P.A. DeBarry, and L.E. Johnson. 2001. GIS and Distributed Watershed Models. II: Modules, Interfaces, and Models. *Journal of Hydrologic Engineering* 6 (6): 515-523.

Summary:
        This paper describes some popular GIS-based hydrologic applications used for processing GIS data for use in spatially explicit hydrologic models. Descriptions are given of some of these common spatially distributed models widely cited in scientific literature, that take advantage of geospatial GIS data, and are used for practical application or research purposes. This discussion proves valuable to agencies and firms wishing to adopt GIS data and technologies for hydrologic modeling and analysis. Issues related to successful implementation of GIS-based hydrologic analysis tools and models are discussed along with current trends and future developments in GIS module and distributed hydrologic models. A brief overview is provided of the major contributing papers outlining the use and some reviews of GIS and hydrologic modeling including water quantity and quality modeling, land use change impacts on watershed responses, hydrologic applications of GIS, GIS-based hydrologic risk assessment, hydrologic model parameter estimation using GIS data and technologies, and hydrologic modeling within GIS packages. A discussion is provided of GIS software packages and GIS application modules or extensions that capture, create, and store hydrologic features in GIS format, or preprocess GIS data for use in hydrologic models. These include ARC/INFO

Hydrologic Routines, the Geographic Resource Analysis Support System (GRASS) GIS, GIS/HEC-1 Interface Module (Prince William County Model), HEC-GeoHMS, HECPREPRO and CRWR-PrePro, TOPographic PArameteriZation (TOPAZ), and Watershed Modeling System (WMS). Spatially distributed conceptual and physically based hydrologic model capable of using GIS data as input discussed here include AGNPS98 developed by the US Department of Agriculture Agricultural Research Service and Natural Resources Conservation Service, CASC2D developed at Colorado State University, HEC-RAS (River Analysis System) and HEC-HMS (Hydrologic Modeling System) developed by Hydrologic Engineering Center of the U.S. Army Corps of Engineers, Modular Modeling System–Precipitation Runoff Modeling System (MMS/PRMS) (U.S. Geological Survey), Systeme Hydrologique European (SHE), Soil Water Assessment Tool (SWAT), and TOPMODEL developed at the University of Lancaster, U.K.. GIS based watershed modeling and assessment applications may be implemented into and managed by an agency or organization through a planned, operation wide GIS accessible to all users, through a GIS in-house service center maintained by a specific GIS group, or through GIS tools imbedded in an organization's specialized applications. None of the models listed here can be applied universally; each model has appropriate applications that satisfy its assumptions, mathematical representation of watershed hydrology, and limitations. An increase in the availability of spatially distributed, GIS based data is the driver for more widespread development and application of GIS-based hydrologic models and data modules. The robust data management capabilities of GIS and current processing abilities of today's computers offers an attractive incentive for the further development and use of spatially distributed hydrologic models in many application arenas. Benefits of using GIS in watershed and hydrologic analyses and application include improved accuracy, reduced duplication, convenient data and map storage and sharing, flexibility, effectiveness and efficiency, and higher product complexity. Current trends in government agencies and private firms have shown an embrace of GIS-based technology, with the potential for the ease of merging hydrologic and watershed analyses with existing GIS databases and applications.

Spatial Extent:
Any user-defined watershed based on the desired position of the outlet up to the size limit of the model.

SAB Reporting Categories:
Chemical and Physical Characteristics (Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Surface and Groundwater Flows)

GIS Tools:
GIS data preprocessing modules: ARC/INFO Hydrologic Routines, the Geographic Resource Analysis Support System (GRASS) GIS, GIS/HEC-1 Interface Module (Prince William County Model), HEC-GeoHMS, HECPREPRO and CRWR-PrePro, TOPographic PArameteriZation (TOPAZ), and Watershed Modeling System (WMS). Hydrologic and water quality models: AGNPS, CASC2D, HEC-RAS, HEC-HMS, MMS/PRMS, SWAT, SHE, SWAT, and TOPMODEL.

### o. Soil Water Assessment Tool (SWAT)

Neitsch, S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams, and K.W. King, 2002. *Soil Water Assessment Tool (SWAT) Theoretical Documentation, Version 2000*. [Online] Retrieved 05/26/2004 at http://www.brc.tamus.edu/swat/.

Summary:

The Soil and Water Assessment Tool (SWAT) is a watershed scale, physically based, computer hydrologic model that predicts the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time.  SWAT uses readily available data inputs including GIS based data in a computationally efficient manner for the simulation of large watersheds, and SWAT enables users to study long term impacts of pollutant buildup in the system and downstream impacts through the use of long term, continuous model simulations comprised of calculations made at daily time steps.

SWAT allows a number of different physical processes to be simulated in a watershed at different spatial extents. For modeling purposes, a watershed may be partitioned into a number of sub-watersheds or sub-basins, which are further subdivided into hydrologic response units (HRUs) that are lumped land areas within the sub-basin that are comprised of unique land cover, soil, and management combinations. SWAT simulates the land based hydrologic cycle using a water balance equation that accounts for precipitation, soil water, surface runoff, evapotranspiration, and return flow.

Climate variables consisting of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity provide the moisture and energy inputs that control the water balance and the relative importance of each component of the hydrologic cycle. A weather generator disaggregates monthly climate variables into daily values for each sub-basin without spatial correlation between sub-basins.

The individual components of the land based hydrologic cycle are modeled in SWAT accounting for vegetation canopy storage or interception of precipitation whereby the excess falls to the land surface where it is infiltrated into the soil potentially redistributed within the soil after a precipitation event stops, or is moved out of a HRU by subsurface lateral flow. Precipitation not intercepted or infiltrated is moved over the land surface via surface runoff. Water that infiltrates and is redistributed may evaporate from the soil surface and return to the atmosphere along with water evaporated from lakes, ponds, and vegetation surfaces.

SWAT includes a plant growth model to simulate all types of land covers, differentiating form perennial and annual plants, and assesses the removal of water and nutrients from the plant root zone, transpiration and biomass/yield production. Erosion and sediment yield is modeled using the Modified Universal Soil Loss Equation with the runoff amount from the land surface facilitating the simulation of erosion and sediment yield. The movement and transformation of nitrogen and phosphorus throughout a watershed are modeling following the nitrogen and phosphorus cycles with nutrient introduction and transport by surface runoff and lateral subsurface flow. Pesticide

movement into the stream network, and into soils and groundwater via percolation are simulated also.

Flood water, nutrient, and pesticide loadings are calculated for the main channels and routed through the stream network to the outlet of the watershed preserving the channel mass flow, and simulating in-channel chemical transformations. Loadings can be routed through reservoirs (ponds or lakes) defined within the HRUs with the calculation of a water balance consisting of inflow, outflow, precipitation, evaporation, seepage, and diversions.

SWAT is best used for large watersheds and could be applied at regional spatial extents incorporating one or many ecoregions. Moreover, readily available GIS data layers can be used as input to SWAT. The division of sub-basins into HRUs provides a semi-disturbed representation of model outputs of loadings for floodwaters, nutrients, and pesticides. SWAT could be used to develop Total Maximum Daily Loads for a region based on specific nutrients or chemical pesticides, with spatially explicit simulation results showing potentially important conservation areas within the region that have not been impacted greatly by nutrient loadings or pesticide overuse. Model results would identify areas within a watershed that need remediation measures to low nutrient and pesticide loadings to the stream network and surface waters.

Spatial Extent:
Well-suited to large (greater than about 1000 km2) watersheds.

SAB Reporting Categories:
Chemical and Physical Characteristics (Physical Parameters, Trace Inorganic and Organic Chemicals, Other Chemical Parameters, Nutrient Concentrations); Hydrology and Geomorphology (Dynamic Structural Characteristics, Sediment and Material Transport, Surface and Groundwater Flows)

GIS Tools:
SWAT. Physically based, spatial distributed hydrologic, water quality, and plant growth ecosystems model.

## p.  Woolhiser- Kinematic Runoff and Erosion Tool (KINEROS)

Woolhiser, D.A.. 1990. *Kinematic Runoff and Erosion Tool (KINEROS)*. [Online] Retrieved 05/27/2004 at www.tucson.ars.ag.gov/kineros.

Summary:
The kinematic runoff and erosion model (KINEROS) is a physically based, computer hydrologic model that simulates for a single precipitation event the processes of interception, infiltration, surface runoff and erosion from small agricultural and urban watersheds. A watershed is divided into planes or surface and channels, in which water flows over planes representing the land surface and into the channel network where it is routed to the outlet. The spatially explicit nature of KINEROS allows for the spatial variation in rainfall, infiltration, runoff, and erosion parameters. Uses include determining

the effects of various artificial features such as urban developments, small detention reservoirs, or lined channels on flood hydrographs and sediment yield.

Precipitation can be input from multiple rain gauges represented by a single pair of x,y coordinates and the spatial and temporal variability of rainfall is expressed by interpolation of precipitation measured at each gauge location. Interception of precipitation by vegetative surfaces is simulated using numerical parameters for interception depth, the average depth of rainfall retained by vegetation, and the fraction of the surface covered by intercepting vegetation. KINEROS contains a dynamic model based on soil physics for simulating infiltration of precipitation reaching the land surface into the soil profile. The infiltration equation represents the soil profile as either one or two layered with the option for water redistribution during periods of hiatus from direct precipitation, and requires parameters for infiltration capacity, hydraulic conductivity, and infiltrated depth of water in the soil. Land surface slope and length, and hydraulic resistance parameters as well as the rainfall intensity and soil infiltration characteristics control the overland flow of surface runoff. Water begins to runoff from the and surface by precipitation exceeding the infiltration ability of the soil, and by the restriction of downward water flow whereby the surface layer of soil fills its available porosity to absorb water. Water flow in the channel network is represented by unsteady, free flowing water with time-varying contributions along channel lengths from the overland planes, and from upstream channel segments. Many types of channel cross-section geometries can be specified and flow through closed urban channel systems is represented. KINEROS can simulate the movement of eroded soil along with the movement of surface water accounting separately for erosion caused by raindrop energy and erosion caused by flowing water.

SAB Reporting Categories:
Chemical and Physical Characteristics (Physical Parameters); Hydrology and Geomorphology (Dynamic Structural Characteristics, Sediment and Material Transport, Surface and Groundwater Flows)

Spatial Extent:
Applicable to small (less than about 100 km2) watersheds.

GIS Tools:
Physically based, spatially distributed watershed model KINEROS.


**12) Kurt Riitters et al.- Multi-scale Analysis of Forest Fragmentation**

Riitters, K.H., J.D. Wickham, R.V. O'Neill, K.B. Jones, E.R. Smith, J.W. Coulston, T.G. Wade, and J.H. Smith.  2002.  Fragmentation of continental United States forests. *Ecosystems* 5: 815-822.

Kurt Riitters et al. (2002) have developed a multi-scale synoptic analysis of forest fragmentation for the conterminous United States.  National Land Cover Data (30-meter resolution), based on Landsat Thematic Mapper data from 1992, was used for the

analysis.  The original 21 classes of land cover were reclassified as forest, non-forest, water or bare rock land cover classes.  A fragmentation model was used to measure area density and connectivity of all forest pixels within a square analysis window called a "landscape." To complete a multi-scale analysis, area density and connectivity were measured at five landscape sizes: 2 ha, 7 ha, 66 ha, 590 ha, and 5314 ha.

## 13) Conservation Biology Institute- Forest Intactness Database

Conservation Biology Institute.  Date unknown.  *Forest Intactness Database*.  [Online]  Retrieved May 10, 2004 at  http://www.consbio.org/cbi/applied_research/intactness/intactness.htm.

Heilman, G.E. Jr., J.R. Strittholt, N.C. Slosser, and D.A. DellaSala. 2002. Forest fragmentation of the conterminous United States: assessing forest intactness through road density and spatial characteristics. *BioScience* 52: 411-422.

The Conservation Biology Institute, the World Wildlife Fund U.S., and the World Resources Institute's Global Forest Watch collaborated to develop the Forest Intactness Database.  The relative forest intactness of 39 forested ecoregions of the conterminous United States was assessed using Landsat Thematic Mapper based National Land Cover Data (NLCD); 1:100,000 scale USGS TIGER road data; 1:100,000 scale U.S. national boundaries; and Bureau of Transportation 1:100,000 scale urban areas.  The original 30-meter resolution NLCD was reclassified from 21 potential classes to either forest or non-forest.  The forest classes included coniferous, deciduous, mixed forest, and woody wetland.  The non-forest classes included water and all other classes.  Forest intactness was mapped within land units that intersected a forest ecoregion and were defined by roads (U.S. interstates, US routes, and state and county highways); urban areas containing more than 50,000 people; and areas greater than or equal to 2,000 hectares.  Road density was calculated for each land unit and a suite of fragmentation metrics were calculated using FRAGSTATS, a spatial analysis software program.  Ordinal scores were assigned to five metrics: road density, class area, percentage of landscape, total core area index, and mean nearest neighbor.  The ordinal scores were summed producing a composite for each land unit.  The assessment identifies remaining relatively intact forest, identifies land units that are suitable restoration candidates within a regional context, and examines forest fragmentation resulting from roads.  Forest Intactness Data is available on CD-ROM and may be ordered from the following:

Conservation Biology Institute
260 SW Madison Ave., Suite106
Corvallis, OR 97333

## 14) Landscape Metrics Software Packages: FRAGSTATS and APACK

### a. FRAGSTATS

McGarigal, K. 2003. *FRAGSTATS: Spatial Pattern Analysis Program for Categorical Maps*. [Online] Retrieved May 18, 2004 at http://www.umass.edu/landeco/research/fragstats/fragstats.html.

McGarigal, K., and B. J. Marks. 1995. *FRAGSTATS: Spatial Pattern Analysis Program for Quantifying Landscape Structure*. USDA For. Serv. Gen. Tech. Rep. PNW-351.

In 1995, researchers at Oregon State University released FRAGSTATS, a spatial pattern analysis program that is designed to quantify landscape structure. Users of the program may define landscape subjects for analysis. The program offers a variety of landscape metrics including patch density, size and variability metrics, edge metrics, shape metrics, core area metrics, diversity metrics, contagion metrics, and interspersion metrics. The original version, version 2, exists in both a vector version and a raster version. The vector version is an Arc/Info AML that was developed using Arc/Info version 6.1, and it will not run with earlier versions of Arc/Info. The raster version is a stand-alone program. Both the vector version and the raster version of version 2 respond to command line input. Nearest-neighbor metrics may only be computed with the raster version. The newest version of FRAGSTATS, Version 3, was developed by researchers at the University of Massachusetts. It is a stand-alone program for use with the Windows Operating environment. Similar to version 2, version 3 accepts input images in a variety of formats including Arc Grid, Ascii, ERDAS, EDRISI, and Binary; however, it is limited to raster formats only. Some of the updated features of version 3 include a graphical user interface, new landscape metrics, and a moving window analysis option. Version 3 is available for download at the University of Massachusetts Landscape Ecology Program website (http://www.umass.edu/landeco/research/fragstats/fragstats.html). Version 2 may be downloaded from an ftp server at Oregon State University. Instructions for downloading version 2 are available on the University of Massachusetts website listed above.

### b. APACK

http://landscape.forest.wisc.edu/projects/apack/

Landscape ecologists rely on landscape metrics to compare landscapes, evaluate temporal changes, and predict landscape pattern effects. Programs that analyze large data sets in an efficient manner are needed. Our objective was to develop a computationally efficient program to calculate landscape metrics. APACK is an analysis package designed to meet these needs. It is a standalone program written in C++ that calculates landscape metrics on raster files. It runs on the Windows 95/98/NT/2000 platforms. UNIX versions are being considered. Data formats supported include ERDAS GIS files and ASCII files. Output data consists of a text file and a spreadsheet readable file that can be further

analyzed. APACK can calculate 25 metrics useful for determining landscape characteristics such as basic measures (e.g., area), information theoretic measures (e.g., diversity), shape measures (e.g., fractal dimension), textural measures (e.g., lacunarity), probabilistic measures (e.g., electivity), and structural measures (e.g., connectivity). In tests versus other commonly used analysis packages APACK was able to calculate upon larger maps and was significantly faster. This is in part due to APACK only calculating those metrics specified by the user. APACK fills the need for an analysis package that can easily and efficiently calculate landscape metrics from large raster maps.

## 15) Missouri Resource Assessment Partnership (MoRAP) Projects

### a. Aquatic GAP Pilot Project

Missouri Resource Assessment Partnership.  2004.  *MoRAP Project: Aquatic GAP Pilot Project.*  [Online] Retrieved May 26, 2004 at http://www.cerc.cr.usgs.gov/morap/projects.asp.

The Missouri Resource Assessment Partnership (MoRAP) is currently working to develop an approach to setting conservation priorities in Missouri.  Goals of MoRAP's project, the Aquatic GAP Pilot Project, include the identification of aquatic biodiversity at regional, watershed, and valley segment scales; the identification of the extent to which current management efforts are conserving aquatic biodiversity; and the identification of methods for integrating terrestrial and aquatic biodiversity assessments.  A 6-step process for identifying and prioritizing aquatic biodiversity conservation targets has been developed and includes 1) map species distributions on a watershed by watershed basis, 2) classify riverine ecosystems into distinct ecological units at multiple spatial scales, 3) document the general habitat affinities or requirements of each species, 4) predict and map the distribution of each species (by stream segment) throughout the watersheds in which they occur, 5) develop coarse-scale conservation priorities (by Aquatic Ecological System) for each Ecological Drainage Unit, and 6) develop fine-scale conservation priorities (by Valley Segment Type) for each Ecological Drainage Unit.  Work is currently progressing for steps 1-4.  Biological databases for use in the project are nearly complete and include fish, mussel, crayfish, and snail databases.  Statewide distribution maps for all riverine species of fish, mussels, and crayfish have been developed.  Geospatial data layers that are widely available across the U.S. are being used in the classification process of Missouri riverine ecosystems, and ArcView and ARC/INFO are being used for mapping.  Further information about this project may be obtained from Scott Sowa at (573) 441-2791 or scott_sowa@usgs.gov.

### b. Opportunity Area Assessment

Missouri Resource Assessment Partnership.  2004.  *An Ecoregion-based Conservation Assessment and Conservation Opportunity Area Inventory for the Lower Midwestern USA.*  [Online] Retrieved May 26, 2004 at http://www.cerc.cr.usgs.gov/morap/projects.asp.

The Missouri Resource Assessment Partnership (MoRAP) Opportunity Area Assessment project is a GIS assisted ecoregion-based conservation assessment that was developed for the four Midwestern states, Iowa, Kansas, Missouri, and Nebraska. There were three main goals of the project: 1) assess environmental quality of all ecological subsections that intersect Iowa, Kansas, Missouri, and Nebraska; 2) provide a finer-resolution data layer that shows the location and extent of conservation opportunity areas (OAs) within the region; and 3) provide an example of how the OA data layer can be used in conjunction with other data relevant to conservation targets, landform representation, and conservation planning. Data from the National Land Cover Database (NLCD), derived from 30-meter resolution Landsat 7 Thematic Mapper imagery, was used to calculate land cover metrics by ecological subsection. Land cover metrics were combined with other variables including digital elevation models (DEMS) and streams data from the 1:100,000 scale National Hydrography Dataset. Three land cover-derived metrics were used to calculate an overall environmental quality index for each subsection and included anthropogenic vegetation along streams, a human use index, and cropland on more than 5% slope. A land cover grid was combined with TIGER roads data to identify conservation OAs, which were defined by the distance of forest, grassland, shrubland, or mosaic patches from roads. MoRAP is currently working to refine this assessment to develop finer resolution models that would allow the assignment of overall biological significance to each 30-m pixel on an ecoregional basis. For more information about this project contact Dr. David D. Diamond at david_diamond@usgs.gov.

## 16) Canaan Valley Institute and Natural Resource Analysis Center at West Virginia University- Landscape Analyst Extension

Canaan Valley Institute. 2004. *Canaan Valley Institute.* [Online] Retrieved May 26, 2004 at http://www.canaanvi.org/

Strager M., P. Claggett, E. Clifton, J. Fletcher, P. Kinder, D. Kemlage, R. Pomponio, T. Schroeder, M. Sherald, J. Strager, and C. Yuill. Date unknown. *Landscape Assessment Tools: Integrating Science and Data for Decision Support.* [Online] Retrieved May 27, 2004 at http://gis.esri.com/library/userconf/proc01/professional/papers/pap476/p476.htm

The Canaan Valley Institute (CVI) and the Natural Resource Analysis Center at West Virginia University have developed an ArcView extension, Landscape Analyst, which allows current conditions of watersheds, counties, and regions to be evaluated using water quality, wildlife habitat, and overall landscape condition indicators. Potential impacts of user-defined or modeled future landscape changes may also be evaluated using the extension. Users of the extension must have the Spatial Analyst extension loaded on their systems. Many of the capabilities of the extension may be accomplished with ArcView and the Spatial Analyst extension alone; however, Landscape Analyst simplifies specialized functions into an easy-to-use interface. Potential applications of Landscape Analyst include cumulative impact assessments, landscape ecological analyses, comprehensive planning efforts, and natural resource management. The first

step in using the extension is to load appropriate data layers into a configuration file, which may include the following: digital elevation model (DEM), land use/ land cover, flow direction, flow accumulation, raster stream, runoff, cumulative runoff, and Strahler stream raster data layers.  The following vector data layers may also be loaded: study area, roads, streams, and water samples.  The next step is to choose a study area, which may be selected by on-screen digitizing, by interactively drawing a graphic around a feature, selecting a subset from a larger data layer or inputting coordinates.  Potential study areas are not limited to the CVI service area (the Mid-Atlantic Highlands of Maryland, Pennsylvania, West Virginia, and Virginia).  Once a study area has been selected, water quality, landscape, or wildlife analyses may be accomplished.  The water quality modeling component of the extension allows development of the following models: expected mean concentration, fate transport, potentially affected streams, delineation of watersheds, and erosion models.  Water quality indicators include riparian forest, agriculture near streams, and stream/road intersections.  The landscape modeling component of the extension may be used to create the following models: development model, landuse/landcover histogram, and tabulation of land use/land cover area.  Landscape indicators include percent forest cover, percent forest within the largest forest patch, percent forest edge habitat, percent streams flowing through forests, human use index, road density, roads along streams, population density, population change, and soil loss potential.  Wildlife indicators include a bird community index, which provides a measure of terrestrial habitat quantity and quality, and Louisiana waterthrush habitat.  For further information contact:

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**17) Carbon Sequestration Potential Projects**

**a.  Falloon et al.- Regionally Estimating Carbon Sequestration Potential**

Falloon, P.D., P. Smith, J.U. Smith, J. Szabó, K. Coleman, and S. Marshall.  1998.
        Regional estimates of carbon sequestration potential: linking the Rothamsted
        Carbon Model to GIS databases.  *Biol Fertil Soils* 27: 236–241.

        Falloon et al. (1998) have modified the Rothamsted Carbon Model with data from
the Global Change and Terrestrial Ecosystems Soil Organic Matter Network (GCTE
SOMNET) to allow the model to be used for regional carbon studies.  The GCTE
SOMNET was established in 1995 to facilitate predictions of changes to soil organic
matter (SOM) caused by changes in land use, agricultural practice, and climate.  In the
study described in this paper, a GIS containing information on soils, land use and climate
was linked to dynamic simulation models for the turnover of organic carbon.  This
allowed the estimation of impacts of land use and climactic changes on carbon stocks in
soil.  The study area of the project was a 24,804 km² area of Hungary.  The soils data that
was used was obtained from the 1:500,000 scale Hungarian HunSOTER database.  The
land use data was obtained from the 1:100,000 scale CORINE database for Hungary.
The climate data that was used was long-term mean monthly temperature, rainfall, and
evaporation data from 1931-1960.  A point data layer was created containing long-term
averaged meteorological data and site locations.  Similar carbon models to the
Rothamsted Carbon Model have been used elsewhere as well.  The CENTURY model
has been applied to agroecosystems in the central United States, and the model, EPIC,
has been used to estimate tillage impacts on the U.S Corn Belt.  The method described in
this paper (using GIS to link spatially explicit data to dynamic simulation models) allows
flexible manipulation of data, graphical display of spatial data, and allows the input of
high-resolution site-specific data.

**b.  Mickler et al.- Modeling and Spatially Distributing Forest Net Primary
      Production at the Regional Scale**

Mickler, R.A., T.S. Earnhardt, and J.A. Moore.  2002.  Modeling and spatially
        distributing forest net primary production at the regional scale.  *J. Air & Waste
        Manage. Assoc.* 52: 407-415.

        Mickler et al. (2002) describe the use of satellite image analysis for inventory and
monitoring of terrestrial carbon.  The information required to estimate the carbon
emission and sequestration potential of forestry-related land use activities cover types
includes spatial distribution, rates of change of forest characteristics, and forest inventory.
Mickler et al. evaluate the use of Landsat Thematic Mapper (TM)-derived land cover data
and USDA Forest Service Forest Inventory and Analysis (FIA) data combined with a
forest productivity model (PnET-II) to generate estimates of carbon storage for
evergreen, deciduous, and mixed-forest classes.  Input data required for the PnET-II
model includes monthly climate parameters, soil water holding capacity (WHC), and
species- or forest-type specific vegetation parameters.  Datasets were projected to Albers

projection, NAD83 datum, GRS1980 spheroid, with a spatial resolution of 98.4 ft². The study area included 534,523,000 acres and 13 states in the southern United States from the Atlantic coast west to Texas and Oklahoma.

### c. Midcontinent Interactive Digital Carbon Atlas and Relational dataBase (MIDCARB)

Midcontinent Interactive Digital Carbon Atlas and Relational dataBase (MIDCARB). 2004. *MIDCARB*. [Online] Retrieved May 12, 2004 at http://www.midcarb.org/.

The Midcontinent Interactive Digital Carbon Atlas and Relational dataBase (MIDCARB) is a research consortium comprised of the State Geological Surveys of Illinois, Indiana, Kansas, Kentucky, and Ohio. It receives funding from the U.S. Department of Energy through the National Energy Technology Laboratory. The purpose of MIDCARB is to evaluate the geologic carbon sequestration potential of its member states. In order to share its findings with decision-makers and the general public, the Consortium is in the process of establishing the online Relational Database Management System and Geographic Information System, which may be used to analyze spatial relationships and technical characteristics of large point sources of carbon dioxide and geologic sequestration options. The data may be maintained at a local level but may be accessed through a single web portal. MIDCARB is expanding the online database to a national version called, "NATCARB."

### d. U.S. Department of Energy- Regional Carbon Sequestration Partnerships

Office of Fossil Energy, U.S. Department of Energy. 2004. *Carbon Sequestration- Regional Partnerships*. [Online] Retrieved May 12, 2004 at http://www.fe.doe.gov/programs/sequestration/partnerships/.

The U.S. Department of Energy has created a nationwide network of federal, state and private partnerships to determine suitable technologies, regulations, and infrastructure for future carbon sequestration. The regional partnerships include the West Coast Regional Carbon Sequestration Partnership, the Southwest Regional Partnership for Carbon Sequestration, the Northern Rockies and Great Plains Regional Carbon Sequestration Partnership, the Plains CO2 Reduction Partnership, the Midwest Geologic Sequestration Consortium, the Southeast Regional Carbon Sequestration Partnership, and the Midwest Regional Carbon Sequestration Partnership. Several of the regional partnerships will identify carbon dioxide sources and sinks and enter data into a GIS database to assess carbon dioxide capture and transport. Efforts include the development of soils and forestry databases that estimate current carbon levels and the advancement of carbon sequestration potential models that estimate current and future agriculture and forest soil/biomass carbon levels.

**18) Spatially Explicit Population Viability Assessment Software**

**a. RAMAS GIS**

RAMAS GIS is designed to link GIS maps of habitat for a species with a metapopulation model for population viability analysis and extinction risk assessment. Habitats used by most species are becoming increasingly fragmented, requiring a metapopulation modeling approach to risk analysis. Recognizing habitat patchiness from an endangered species' point of view requires spatial information on habitat suitability. RAMAS GIS meets both these requirements by linking metapopulation modeling with landscape data and GIS technology.  See: http://www.ramas.com

**b.  PATCH (Program to Assist in Tracking Critical Habitat)**

Schumaker, N. H. 1998. A Users Guide to the PATCH Model. EPA/600/R-98/135. U.S.
    Environmental Protection Agency, Environmental Research Laboratory,
    Corvallis, OR.

PATCH is a spatially explicit, individual-based, life history simulator designed to project populations of territorial terrestrial vertebrate species through time.  PATCH generates estimates of a wildlife population size, distribution, and trends. The model permits landscapes to change with time. Model inputs include species' habitat and area requirements, vital rates, and movement ability. Model outputs include tabular measures of population size, and maps of population distribution. Future version of PATCH will address a wider range of species life history traits, stressor scenarios, and species interactions.

**19) Other Projects, Analytical Techniques, and Tools From The Scientific Literature**

**a.  Bruinderink et al.- LARCH Landscape Ecology Model**

Bruinderink, G. G., T. Van Der Sluis, D. Lammertsma, P.Opdam, and R. Pouwels.  2003.
    Designing a coherent ecological network for large mammals in northwestern
    Europe. *Conservation Biology* 17(2): 549-557.

Bruinderink et al. (2003) have developed a landscape ecology model to identify the structure of an ecological network for large mammals in the Netherlands, Belgium, and adjacent parts of France and Germany.  The red deer was chosen as a focal species because of its widespread distribution, key role in ecosystem functioning, and large home-range size.  A potential habitat network was identified for the red deer based on available natural habitat.  Spatial distributions of prohibitive factors to establishing a sustainable network were also identified.  Then maps were developed to show opportunities for linking the remaining natural areas into an ecological network that would enable local populations to form a metapopulation.  Geographic information

system datasets that were used included the CORINE land-cover data (250 m x 250 m cell size) and roads from Digital Chart of the World.  Other data included main forage types of the red deer (dry matter percentage of diet), forage availability in the area (percent coverage), and digestibility of forage by red deer (percent) to calculate total available digestible organic matter.  The LARCH (Landscape Ecological Rules for the Configuration of Habitat) landscape ecology model was used as a tool.  This model uses landscape characteristics that are ecologically scaled in relation to the spatial requirements of a species.  Steps of the LARCH model include 1) use land cover data to group patches of habitat that are within the home-range distance of the red deer, 2) calculate available digestible organic matter to assign a carrying capacity to each patch 3) account for barrier effect of roads, 4) calculate the spatial connectivity of the network.

## b.  Clench-Aas et al.- Air Quality Monitoring System

Clench-Aas, J., A. Bartonova, T. Bøhler, K. E. Grønskei, B. Sivertsen, and S. Larssen.
 1999.  Air pollution exposure monitoring and estimating-Part I. Integrated air
 quality monitoring system. *J. Environ. Monit*. 1: 313–319.

This paper presents an air quality monitoring system that uses GIS and allows the identification of geographical areas whose inhabitants are exposed to ambient pollution.  Additionally, the system allows the following: identification of the number of people exposed to concentrations that exceed air quality guidelines; description of the exposure of population subgroups; planning of pollution abatement measures; establishment of risk assessment and management programs; and investigation of short- and long-term effects of pollutants and pollution sources on human health.  The system is based on a dispersion model, EPISODE, which accounts for both stationary and mobile sources of pollution.

## c.  Dettmers and Bart- Using "Presence" Data to Construct Spatially Explicit Habitat Models

Dettmers, R. and J. Bart.  1999.  A GIS modeling method applied to predicting forest
 songbird habitat. *Ecological Applications* 9(1): 152-163.

Dettmers and Bart (1999) have described an approach for using "presence" data to construct spatially explicit habitat models.  The approach is comprised of two steps: 1) identify an optimal range of values for each habitat variable and 2) construct multivariate models of good habitat.  Species-specific habitat models for nine forest-breeding songbirds in southern Ohio were developed.  The models were based on species' microhabitat preferences, which can be predicted by abiotic variables.  The variables used in this study include slope, land surface morphology, land surface curvature, water flow accumulation downhill, and an integrated moisture index, in conjunction with a land-cover classification that identifies forest/nonforest.  The existing National Land Cover Data (NLCD) derived from 1986 Landsat Thematic Mapper imagery was used to distinguish forest from non-forest classes.  The integrated moisture index was a function of solar radiation, relative slope position, surface curvature, and water holding capacity of the soil.  A 1:24,000 scale digital elevation model (30-meter resolution) was used to

calculate slope, land surface morphology, land surface curvature, and water flow accumulation downhill. The approach failed to identify small proportions of the study area where large proportions of the species existed because several variables that affect avian densities were left out of the study such as food availability, interspecific competition, and predator abundance. The authors suggest that future methods for habitat modeling make optimal use of biological insights and statistical methods.

### d. Ferrier- Using Biodiversity Surrogates in Regional Conservation Planning

Ferrier, S. 2002. Mapping spatial pattern in biodiversity for regional conservation planning: where to from here? *Syst. Biol.* 51(2): 331-363.

Biodiversity surrogates are commonly used to achieve a representation of spatial pattern for the purpose of regional conservation planning. Ferrier (2002) divides the surrogates into three main categories ranging from fine-filter to course-filter, respectively: 1) distributional data for selected taxa, 2) modeled biological distributions, and 3) remote environmental mapping. At the landscape scale, land-class maps of ecosystems and vegetation types are available for the entire planet at a medium-scale (1 km² grid resolution) and more detailed resolution is available in many regions. At the ecosystems and natural communities scale, classification of survey data to derive communities or assemblages is used. Models that relate species richness to remotely mapped environmental variables may be used. Ferrier proposes that modeling of differentiation diversity through generalized dissimilarity modeling (GDM), which uses both biological survey data and remotely derived environmental variables (rainfall, temperature, etc.) is possible. To map species, species locational records (survey or collection data) or interpolation of distribution through range maps may be used. Modeling distributions of individual species in relation to mapped land-classes may be used. Ferrier discusses problems inherent with relying on the surrogates used to represent spatial pattern and suggests three strategies for making more effective use of biological data and knowledge for the purpose of mapping spatial pattern in biodiversity. The first strategy is to more closely integrate biological and environmental data through predictive modeling, with increased emphasis on modeling collective properties of biodiversity rather than individual entities. The second strategy is to make more rigorous use of remotely mapped surrogates in conservation planning by incorporating knowledge of heterogeneity within land-classes, and of varying levels of distinctiveness between classes, into measures of conservation priority and achievement. The third strategy is to use relatively data-rich regions as test-beds for evaluating the performance of surrogates that can be readily applied across data-poor regions.

### e. Guntenspergen et al.- Using Indicators to Evaluate Wetland Condition

Guntenspergen, G. R., S. A. Peterson, S. G. Leibowitz, and L. M. Cowardin. 2002. Indicators of wetland condition for the Prairie Pothole Region of the United States. *Environmental Monitoring and Assessment* 78: 229–252.

Guntenspergen et al. (2002) describe an approach for developing and evaluating wetland indicators that can be used to assess wetland condition in the Prairie Pothole Region in the United States. The experimental design included selecting a reference condition. It was decided that there are no unimpaired wetlands in the region and wetland condition is strongly associated with surrounding uplands, so uplands were used as a reference. Grassland dominated uplands and cropland dominated uplands were chosen as the two extremes of a land-use gradient in the region with studies having shown that grassland dominated land cover results in less impact on adjacent wetlands than croplands. Methodology adhered to the Environmental Monitoring and Assessment Program (EMAP) integrated quality assurance plan for the Surface Water Resource Group of the Environmental Protection Agency. Indicators were tested to determine their ability to distinguish between the effects of grassland dominated and cropland dominated landscapes on wetland condition in the region. A series of physical, chemical, and biological indicators were chosen including measures of spatial density, area and land use characteristics of wetlands and uplands; measures of seasonal loss of surface water in wetlands; measures of wetland drainage; and estimates of breeding pairs of dabbling ducks. Landscape scale and basin scale indicators were chosen. The landscape scale indicators that were most capable of distinguishing between the two upland land covers chosen were: 1) frequency of drained wetland basins, 2) total length of drained ditch per plot, 3) amount of exposed soil in the upland subject to erosion, 4) indices of change in area of wetland covered by water, and 5) number of breeding duck pairs. The only statistically significant basin scale indictor that was capable of distinguishing between the two land cover types was plant species richness. The authors suggest that landscape scale indicators are more successful than basin scale indicators and that remote sensing can be a useful tool for assessing wetland integrity.

## f. Jensen et al.- A Predictive Vegetation Mapping Process

Jensen, M.E., J.P. Dibenedetto, J.A. Barber, C. Montagne, and P.S. Bourgeron. 2001. Spatial modeling of rangeland potential vegetation environments. *Journal of Range Management* 54(5): 528-536.

Jensen et al. (2001) developed a predictive vegetation mapping process to map fifteen habitat types across the Little Missouri National Grasslands, North Dakota. A total of 616 field plots were used to map and describe habitat types. Data collected at each plot included soil morphology, elevation, geology, landform, landform position, production by lifeform, canopy cover by lifeform, ground cover, canopy cover, and plant height by species, and geographic coordinates derived from topographic maps and global positioning systems (GPS). Raster-based predictor variables were associated with each test plot and included climatic, topographic, and satellite imagery variables. The potential vegetation map was developed using the following steps: 1) identification of the habitat types to be mapped, 2) delineation of appropriate biophysical strata for modeling, and 3) multivariate statistical analysis and development of potential vegetation model rule sets by appropriate strata. The six basic geographic information system (GIS) data themes included landform subsections, existing vegetation lifeforms, climate, terrain, LANDSAT satellite imagery, and habitat type plot locations. The National Land Cover

Data (NLCD) based on Landsat Thematic Mapper imagery was used in the analysis.  A soil-climate interpolation model developed by the USDA, Natural Resource Conservation Service, was used.  Input data included daily temperature and precipitation from local weather stations; soils data from USDA, NRCS, 1:250,000 STATSGO database; and topographic data from a 30 m digital elevation model (DEM).  To evaluate topography, six topographic variables were calculated across the study area using a 30 m DEM.

## g.   Jensen et al.- GIS Tool For Managing Urban Air Quality And Human Exposures

Jensen, S.S., R. Berkowicz, H.S. Hansen, and O. Hertel.  2001.  A Danish decision support GIS tool for management of urban air quality and human exposures. *Transportation Research Part D* 6: 229-241.


A model system, AirGIS, is presented in this paper as a model that estimates ambient air pollution levels at high temporal and spatial resolutions.  It is a GIS that is based on a Danish operational street pollution model (OSPM), technical and cadastral digital maps, and Danish databases on buildings, cadastres, and populations.  It allows mapping of traffic emissions, air quality levels, and human exposures.

## h.  Mladenoff et al.- Validation of a Predictive Spatial Model of Gray Wolf Habitat Suitability

Mladenoff, D.J., T.A. Sickley, and A.P. Wydeven.  1997.  Predicting gray wolf landscape recolonization: logistic regression models vs. new field data. *Ecological Applications* 9(1): 37-44.


Mladenoff et al. (1997) tested a predictive spatial model of gray wolf habitat suitability.  The team tested a model based on logistic regression analysis of regional landscape variables. In northern Wisconsin, wolves were tracked, using radiotelemetry since 1979.  Radiotelemetry data obtained from the Wisconsin Department of Natural Resources was digitized into the ArcInfo GIS.  The US Census Bureau (1991) TIGER/Line roads coverage was used to derive road density.  A previous model tested by the researcher included many variables such as land use/land cover, land ownership/management classes, road density, human population density, and deer abundance; however, the simple logistic regression model using road density tested in this study proved to be a successful predictor of areas most likely to be colonized by wolves.  The model has also been applied to estimate potential gray wolf habitat in the northeastern United States.